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Mine Spoil Potentials for Water Quality and Controlled Erosion

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Mine Spoil Potentials
for Water Quality and Controlled Erosion

by

Division of Plant Sciences
College of Agriculture and Forestry
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Morgantown, West Virginia 26506

for the

ENVIRONMENTAL PROTECTION AGENCY

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Analysis of exploratory test cores and rock chip samples has made available information necessary to the development of rational techniques for reclaiming coal mine spoil for useful purposes. By assigning an area a particular future use and analyzing the rock structure in advance of the surface mining, materials can be assembled and placed in the fill to allow the filled strip mine to revegetate and be developed into a useful area. Oxidation of pyrite materials, source of most acidity below 4.0 in mine spoils, can be controlled by: (1) using clay shales for fill; (2) controlling grain size in the fill; and (3) controlling accessability to exchange of solutes and oxygen. In miniature lysimeters filled with 4 ft of normal, loamy (pH 6.7) soil, no acidity nor iron drained from the bottom from pyrite buried at 6 depths, from 1/2 to 36 inches, during a 24 week test period. Base exchange by the soil neutralized the acid and retained the iron. (Lowry-Texas)

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ABSTRACT

Extensive geologic and soils information and classification provide the basis for applying adapted chemical, physical, and mineralogical measurements to selected rock and soil profiles involved in surface mining, and for expanding results to other points or regions for prevention of acid, sediment, and other pollution.

With Mahoning sandstone, the common weathering depth of 6 meters contains essentially no disseminated pyrite. The originally gray quartzose pyritic sandstone weathers brown, and plant nutrients Ca, Mg, and K are removed by acid leaching. Moderate liming and fertilization of the brown rock and soil enable ground covers to protect spoil surfaces and assure quality waters.

Weathering in spoils, and laboratory simulations, both with and without appropriate chemoautotrophic organisms, reflect rock textures, mineral species, and pyrite oxidation with release of acid. Resulting net acidity or basicity influences soil and water quality.

Old barren spoils confirm that pH is the prime variable associated with lack of vegetation but available water is limiting on sandy, stony spoils.

Fissile iron ore spoils 70 to 130 years old showed that rooting depths and available water capacities were superior to original soils. Site quality for trees or pasture, and water quality were not significantly different between spoils and natural soils.

This report was submitted in fulfillment of Project 14010 EJE under the sponsorship of the Office of Water Programs, Environmental Protection Agency.

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SECTION I

CONCLUSIONS

1. When exploratory test cores and rock chip samples (from rotary drilling of blast holes) are available, it is feasible to study soil and rock properties in advance of surface mining to obtain information needed to guide replacement of the different earth materials most advantageously for water quality and controlled erosion.

2. Studies of coal overburdens in advance of surface mining are most useful when rock structure, stratigraphy, and soils are known well enough to permit generalizations regarding the areal extent of properties measured and rates of change in any specified direction. Our results to date are keyed to Surface Mining Province 2, centered principally in Preston County, West Virginia.

3. Oxidation of pyritic minerals accounts for most acidity below pH 4.0 in variable mine spoils, and presently available native or introduced plants give inadequate ground cover for pollution control unless rooted partly in materials with pH in water slurry greater than 4.0.

4. Greatest concentrations of pyritic sulphur can be tolerated most in clay shales and least in medium or coarse-grained sandstones. This general relationship to rock textures is influenced strongly by essential mineralogy, exchangeable bases, and accessory minerals, especially carbonates.

5. Grain size and dissemination of pyrite influence reaction rate and extent of acid damage. Fine grain size and widespread dissemination characterize some sandstones and explain why small pyrite percentages can be serious unless neutralizing ions or compounds are present. On the other hand, prominent macroscopic pyrite crystals, balls, cleats, wedges, and layers on rock cleavages often have little influence on acidity or toxicity in mine spoils and waters. This is explainable in terms of surface for reactions to occur which (for similar shapes) is inversely proportional to a linear dimension of the particles.

6. In addition to grain size, the reaction rate of pyrite should be influenced by accessibility to exchange of solutes and oxygen. Partial weathering, resulting in coating with iron oxides, probably reduces rates of further oxidation. Lack of accessibility

to Thiobacillus organisms, restricted by oxide coatings or slight permeability of embedding rock, stagnates pyrite oxidation. These tendencies are supported by theory, recent publications, and observations in this study, but quantitative data on oxidation rates in the field are not yet available.

7. A weathered zone is recognized in many stratigraphic sections below soil profiles. In the common case of Lower Mahoning sandstone in Preston County, this weathered zone penetrates consistently to a depth of about 6 meters (20 feet) or deeper along fracture planes within which essentially all pyrite has been destroyed, and the rock color is dominated by yellow and brown (high chroma) of ferric oxide. This provides a depth of material suited to placement on the surface of mine spoils which has no potential mineral acidity or toxicity, although it is leached free of acid soluble plant nutrients. However, it is only weakly buffered since clay percentages are minor and clay species are dominated by kaolinite. Thus, moderate applications of lime and fertilizer enable plants to provide cover, and 25% or more fines between weathered rock fragments hold sufficient available water to support deep-rooted plant species.

8. A weathered zone relatively free of pyrite is the rule in other lithologies of Preston County, but the depth is uncertain and needs to be determined.

9. Since weathered rock formerly rich in pyrite was intensely leached with sulphuric acid during weathering, other subdivisions of geologic sections often contain superior reserves of plant nutrients. In these cases, sufficient information about acid versus basic potentials, and plant nutrient levels should identify placement of spoils that would assure better soil and water than exclusively using rock from the weathered zone.

10. When fine-grained pyrite is abundant (FeS_2 more than about 0.5%) and significant free carbonates are present, especially in slowly permeable clayey soils, sufficient soluble salts (mostly sulphates) may accumulate that plant growth will be inhibited and waters damaged by concentrations of soluble salts. In humid Preston County, West Virginia, accumulations of this type are temporary except where drainage is impeded.

11. Rock and soil colors provide useful field clues to properties and reactions that influence soil and water quality in mine soils. Standard Munsell soil color charts provide a useful means of ex-

pressing colors consistently for interpretion. With Mahoning and Saltsburg sandstones in Preston County, high chromas (greater than 2) indicate staining with iron oxides and likely absence of pyrite or other minerals that are unstable in strongly oxidizing environments. Low chromas (less than 2) occuring well below the subsoil indicate rock that has not weathered and may contain such minerals as pyrite. Alternatively, low chromas can indicate rocks that contain extremely low contents of iron regardless of the oxidation state. However, in lithologies studied, all low chroma soil and sandstone materials that are essentially void of iron occur in the highly weathered zone and are a result of acid leaching.

12. When pulverized pyrite was buried under 3 inches (7.6 cm) or more of normal, slightly acid (pH 6.7) soil in a miniature lysimeter, its rate of oxidation and acid formation was 10 to 25% as great as for pyrite within 1/2 inch (1.2 cm) of the surface. A similar trend should occur under field conditions.

13. In miniature lysimeters filled with 4 feet of normal, loamy (pH 6.7) soil, essentially no acidity nor iron drained out the bottom during 24 weeks with pulverized pyrite buried at 6 depths, from 1/2 inch (1.2 cm) to 36 inches (91 cm). Base exchange by the soil neutralized the acid and retained the iron.

SECTION II

RECOMMENDATIONS

1. Surface miners of Upper Freeport coal in Surface Mining Province 2 should leave only rock and soil from the top 20 feet of the stratigraphic section in the surface foot of the graded spoil. Also, in particular, all thick bedded light gray sandstone (color chroma less than 2 and color value greater than 6) should be buried under at least 6 inches (15 cm) of yellow or brown sandstone or soil (chroma greater than 2).

2. Mine spoils with pH of 4.5 or less by field kit methods should be sampled for testing by an established laboratory before liming, fertilizing, and seeding to forages or ground covers. When such samples are submitted to West Virginia University Soil Testing Services, testing should include calcium, magnesium, total sulphur, color chroma, and lime requirement adjusted for mine spoils, as well as pH, available phosphorus, and available potassium. Moreover, within two years after stand establishment, additional tests should be made and surface treatments applied as recommended to assure stands and good-quality waters.

3. Sulphur profiles and pyrite modes should be determined in stratigraphic sections from the surface down to all major coals being surface mined or considered for surface mining. The sites for such profile studies must be correlated not only with properly identified coals, but with lithologic properties of different subsections of the overburden and local or regional sedimentary trends.

4. Mine spoils should be defined, classified, and mapped more precisely in terms of rock types, water holding relations, profile chemistry, profile mineralogy, and rock weathering trends as well as surface acidity, stoniness and slope. The start that has been made toward inclusion of mine spoils within the comprehensive system of classification for soils at all 6 categoric levels should be pursued and tested as an aid to revegetation and proper management for varied uses without water pollution.

5. Acid neutralizing capacities from carbonates, exchangeable bases, and weatherable minerals should be determined in selected soil and rock profiles in conjunction with determinations of pyrite and potential acidities. In this way, net acidity or basicity for each section can be established and water quality predicted for particular mine spoils.

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6. The hydrogen peroxide method for determining potential acidity, which has worked well with some sandstones and shales, should be tested with a wider range of materials and possibly modified for improved precision and more general usefulness.

7. Methods of distinguishing organic sulphur from pyritic forms should be further tested in shales of variable organic matter and mineralogy as well as coals, and total potentials as well as rates of release of acid from organic forms should be determined.

8. Improved information should be obtained about available water-holding capacities to be expected in mine spoils derived from different geologic materials. With such information, it should be possible to adjust the placement of certain materials in favor of higher water-holding capacities without introducing undesirable acidity or toxicities. In this connection, special attention should be given to the influence of coarse fragments, including their patterns of porosity.

9. The influence of depth of burial of pyritic material under different kinds of rock or soil should be determined more precisely under laboratory and field conditions in relation to microbiological activity and associated physical and chemical variables.

10. Major research effort should be oriented toward formulation of guidelines for sequential placement of available materials to create the best possible soils and water for anticipated future use of mine spoils. For example, some spoils are likely to be needed for camp sites, trailer courts, or for sludge disposal. In all cases, it would be helpful to plan in advance for such uses. Thus, pollution from sewage and related problems could be prevented.

11. Studies of chemistry and mineralogy of lithologic sections in advance of surface mining should include selection and analysis of materials suspected as likely sources of particular toxic elements. For example, we have some suggestions that copper may be soluble in toxic concentrations somewhere in strata being studied, but mineral sources and chemical conditions favoring solubility are not known. In this connection, some sludges considered for filtering in certain mine spoils are known to contain toxic or near toxic concentrations of copper. If accidentially combined, high copper sludges and spoils could result in toxic waters. Other potentially toxic elements that should be considered include mercury, cadmium, selenium and molybdenum.

12. Special workshops should be developed for selected surface miners and field technicians to discuss and review in surface mining regions such subjects as: (1) identification of common rocks, minerals and notable sedimentary features; (2) recognition of prominent soil characteristics; (3) evidences of physical and chemical reactions occurring in different rocks and spoils; (4) identification of certain plants and their interactions with mine spoils; (5) use of Munsell color books and other aids to understanding soil, rock and water chemistry; (6) liming, fertilizing and seeding mine soils; (7) long-range management of mine soils based on comprehensive classification, mapping and on-site investigations.

13. In Surface Mining Province 1, special attention should be given to rock properties that control breakdown into fine particles, and erodibility or gravity slippage on steep slopes. Attention should be given also to plant nutrients needed for vigorous ground covers, but physical stability demands high priority. Rock textures, clay mineral species, exchangeable cations and intergrain cementation should be emphasized with carefully identified and correlated samples representing stratigraphic sections involved in surface mining on steep slopes.

SECTION III

INTRODUCTION

This study was initiated because surface mine spoil reclamation in West Virginia was hampered by a lack of physical, chemical, and mineralogical information about the particular soil and rock material being exposed and placed in spoil deposits in connection with rapidly expanding coal stripping operations. The shortage of information was resulting in delayed or unsuccessful attempts at proper revegetation, with consequent erosion of fine spoil particles and continual exposure of buried material, which in some cases weathered to produce mineral acidity and associated bio-toxic chemicals in soil, runoff and seepage waters.

The West Virginia Department of Natural Resources had authority to require operators to bury potentially acid-forming or toxic earth materials in spoils, and operators were agreeable to carrying out specified requirements, but information was lacking as to which overburden strata were inherently undesirable at or near spoil surfaces. The lack of information about characteristics of the rock in particular geologic sections and how it would react in the environment of spoil deposits thus appeared to be the cause of serious pollution from mine spoils, and no studies promised to remedy the situation. However, active exploration by companies in process of expanding new areas and willingness by these operators as members of the West Virginia Surface Mine Association, to provide test cores, core logs, maps, rock chip samples from blast hole borings, and free access to mining properties provided excellent opportunities to obtain samples and associated information needed to help determine characteristics of soils and diverse rock types.

The general goals of this research has been to provide sufficient information about coal overburdens and spoils to enable operators to place, treat, and manage variable spoils in the most favorable manner to assure water and soils of good quality during surface mining and thereafter.

Specific objectives identified in the project proposal were:

1. To determine certain physical and chemical properties of coal overburden strata that influence suitability of mine spoil for soil formation and unpolluted runoff or seepage water.

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2. To determine processes and rate of physical and chemical change of important spoil properties by natural or induced weathering.

3. To determine interactions between growing plants and properties of spoil and water. This will also include interactions between plants and microorganisms and the influence of microbes on mineral mobility.

4. To determine effectiveness of plant cover, microorganisms and related practices in prevention of erosion, sedimentation, and in reducing acidity and chemical pollution of water from characterized spoil.

5. To improve precision of spoil classification.

This research is unconventional and sometimes unique because it does not fit completely within the bounds of established disciplines. The group of coworkers on this project provided interrelated competence in geology, soils, chemistry, microbiology, and general conservation. Such a group should be able to discover and formulate solutions to water quality problems with mine spoils because their viewpoints and approaches are unhampered by artificial disciplinary boundaries.

SECTION IV

GEOLOGICAL CONSIDERATIONS

Introduction

The following discussion and maps summarize the geological considerations controlling plans for the methodical study of present or likely future mine spoils throughout West Virginia and the selection of the area for commencing a concentrated study during the initial two-year period of research on Mine spoil potentials for water quality and controlled erosion.

The area of principal concentration during the initial phase of study was selected to include the rock section exposed in Preston and parts of Monongalia, Taylor, Mineral, Grant, Tucker and Upshur Counties, or Surface Mining Province 2 (Figure 1). Some additional study of mine spoils was conducted on the eastern edge of Surface Mine Province 3 and correlative rocks exposed locally on high knobs of Surface Mine Province 2 (Figure 1).

The geologic section and the historicity of coal-mining activity are similar throughout the area of Surface Mine Province 2, i.e., coals (Kittanning (locally), Upper Freeport, Bakerstown and Pittsburgh) with suitable overburden, quality and thickness have been mined by underground methods during this century. Currently surface mining of the above coals as well as others (Upper Kittanning, Lower Freeport, Mahoning, Brush Creek, Harlem, Elk Lick and Little Pittsburgh coals) has increased at the expense of underground methods, and it is anticipated that future contributions to the coal economy of the respective counties by surface mining will continue to increase (Appendix C).

The study of mine spoils, described in the following paragraphs, was concentrated in Preston County during the 1969-1971 biennium for the following reasons:

1. The stratigraphic section, reflecting the depositional and the structural history of the Allegheny Mountain Section of the Appalachian Plateau in Preston County, is representative of the larger area included in Surface Mining Province 2.

2. The expansion of surface mining in Preston County in recent years exposed the section for methodical study and sampling of highwalls and spoil banks. In addition, core logs and cores were made available in the flurry

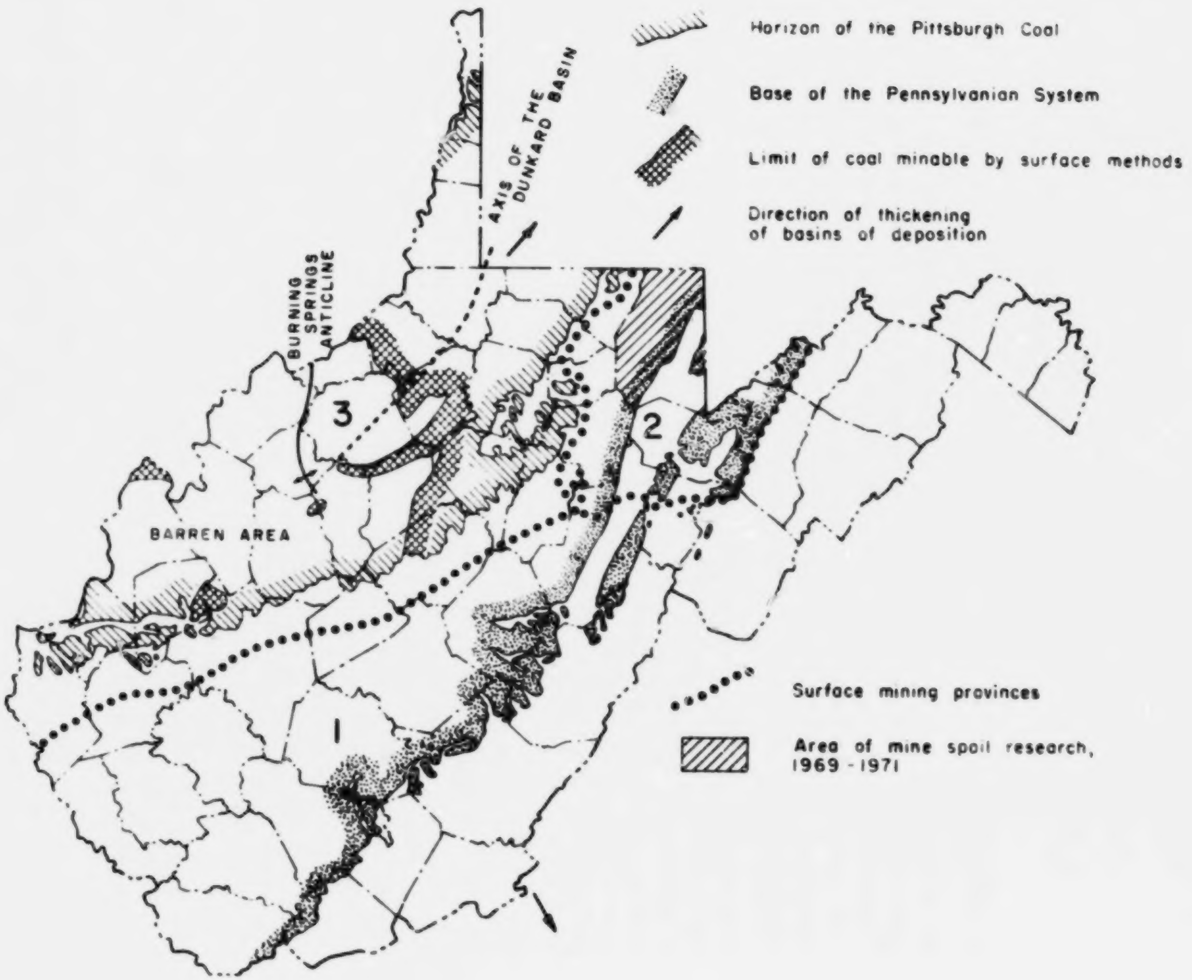
Horizon of the Pittsburgh Coal
Base of the Pennsylvanian System
Limit of coal minable by surface methods
Direction of thickening of basins of deposition
Surface mining provinces
Area of mine spoil research, 1969 - 1971
AXIS OF THE DUNKARD BASIN
BURNING SPRINGS ANTICLINE
BARREN AREA
1
2
3

FIGURE 1. SURFACE MINING PROVINCES IN WEST VIRGINIA

of exploration activity to prove reserves of coal for mining by underground methods and for extension and development of surface mines.

3. The area of Surface Mining Province 2, including Preston County, was subjected to subdued folding (upwarps and downwarps) more intense than other areas of the Pennsylvanian and Permian Systems in West Virginia. The Upper Freeport, the principal coal of Preston County, and other coals and overlying sandstones are exposed on relatively steep slopes leading to upland farming areas. Surface mining has disturbed rather large areas of the farming culture where the overburden is 80 feet (24 meters) thick above the various coals.

4. Mining companies with large land holdings in the area have cooperated fully in providing core, highwall, blast hole, and spoil samples and free access to mining records and properties.

Surface Mining Provinces

Mine spoil research is complicated locally by the diverse nature of the depositional history of at least 6150 feet (1880 meters) (maximum) of rocks of Pennsylvanian and Permian age in West Virginia. Essentially the section is composed principally of quartz and clay with varying quantities of durable sand to fine pebble gravel-sized (generally less than 50 percent of the section) fragments of quartz, quartzite and lesser quantities of chert and other stable rock types, superimposed on the finer clastics. These materials were transported by running water in a northerly direction and distributed in a delta complex by meandering streams and distributaries encroaching inexorably on numerous thinner organic (coal) and chemical (limestone) deposits. Contemporaneous diagenetic as well as subsequent secondary changes occurred to accumulate concentrations of compounds of iron, manganese, and the alkaline earths as well as minor quantities of rarer compounds. Generally, the preferred orientation of diagenetic and secondary accumulations is attributed to the movement, sizing, and distribution of the clastics, however, analysis of trends of concentration of compounds in the deposition of a delta complex must await the extrapolation of detailed physical and chemical data from studies similar to that described on the following pages.

The Pennsylvanian and Permian Systems of West Virginia can be divided into three surface mining provinces based on generalizations of the physiographic, stratigraphic and structural geology of the State (Arkle, 1971) (Figure 1). Surface Mining Province 1 includes the units of the more rapidly subsiding and older basin of deposition of southern West Virginia while Surface Mining Provinces 2 and 3 are restricted to the more stable basin of deposition in northern and western West Virginia. A summary of the characteristics of the respective surface mining provinces follows.

Surface Mining Province 1 is a maturely, deeply dissected plateau area extending northeast across southern and central West Virginia into Randolph County. Except for larger cities and municipalities such as Charleston and Beckley, the population is concentrated along narrow meandering stream valleys. Steep slopes extend from the narrow valleys to inaccessible and rugged ridges, ranging in relief from 600 feet (180 meters) in the Charleston area to as much as 1400 feet (420 meters) farther east in the New River Gorge.

The beds (Pocahontas, New River, Kanawha and Charleston in ascending the section) represent the earlier of two basins of coal deposition during Pennsylvanian time. The basin subsided intermittently and deepened to the southeast. The sediments, essentially a wedge of fine to coarse clastics, were derived from older rocks of the Appalachian region to the south. The coal-bearing facies, the base of which is the southeastern exposure of Pennsylvanian rocks, thins rapidly from the thickest section in southeastern West Virginia to the northwest into massive marine (early) and deltaic (late) sandstones and finally disappears in the subsurface of western West Virginia. The basal New River-Pocahontas formations, 1750 feet (525 meters) in McDowell County, are represented by 400 feet (120 meters) of quartzose sandstones (80 to 100 percent) at Charleston, West Virginia, a distance of 65 miles (104 km). The rate of thinning is about 20 feet per mile (3.8 meters per kilometer) to the northwest. The northwestern boundary of Surface Mining Province 1 drawn on the 1.50 percent sulphur line of composite coal analyses (Lotz, 1970), nearly coincides with the boundary derived from geological considerations (Arkle, 1969, pp. 62-66) including the disappearance of all commercial coals to the northwest.

In addition to the fine-to-coarse clastics in the form of shale and sandstone (the section is approximately 50 percent sandstone) and inconspicuous underclays, a few thin irregular marine and fresh-water limestones are almost entirely confined to the Kanawha formation. It is notable that the sandstones and siltstones, cemented with siderite ($FeCO_3$) and shales, contain numerous small to large (up to 4 feet (1.2 meters) thick or in diameter) sideritic lenses, nodules and stringers, particularly the Kanawha formation.

Of the 70 named coals, some 45, responsible for 70 percent of the coal production in West Virginia, are considered to be commercial coals in some areas of Surface Mining Province 1. The coals responsible for much of the coal production of southern West Virginia are the Pocahontas 3, 4 and 6, Fire Creek, Beckley, Sewell, Eagle, Powellton, Campbells Creek, Peerless, Cedar Groves (Alma, Lower Cedar Grove, and Cedar Grove), Winifrede, Coalburg, Stockton, No. 5 Block and North Coalburg in ascending the section. These as well as numerous other coals of the section, spaced in relatively close intervals on the steep hillslopes, are amenable to surface mining and largely account for the stark devastation of local areas of the countryside of Surface Mining Province 1. The development of coals, conforming to the northwest shift of the basinal configuration in time, reach maximum development farther and farther to the northwest in ascending the section.

Interestingly, the oldest coals, exposed on the southeast, are semi-bituminous, high-carbon, and low-sulphur coals with volatile matter ranging from 13 to 18 percent. The volatile matter increases to greater than 34 percent with a commensurate decrease in carbon content and increases in sulphur content to 1.50 percent in ascending the section to the northwest in the direction of maximum coal development of the youngest coals in Surface Mining Province 1.

Surface Mining Provinces 2 and 3 are in a maturely dissected plateau area, confined to western and northern West Virginia. The area is generally readily accessible hill country. Steep slopes rise from narrow bottom land 500 to 600 feet (150 to 180 meters) to narrow sinuous ridges. The Ohio and Monongahela Rivers have modified contiguous areas. Farther east, the relief increases and the area becomes more mountainous. Broad upland areas, incised by streams of fairly high gradient, forming precipitous slopes and valley walls, are surrounded by rugged mountainous areas.

The beds (Pottsville, Allegheny, Conemaugh and Monongahela of Pennsylvanian age and the Dunkard of Permian age) were deposited in the younger and more restricted of the two basins of coal deposition in West Virginia. This basin shelved in an oval pattern in southwestern West Virginia and subsided gently to the northeast in eastern Ohio, southwestern Pennsylvania, and Maryland.

For this discussion, the section is divided into two groups, each depicting its own unique geologic characteristics. The Lower Group (Surface Mining Province 2) includes the beds of the Pottsville, Allegheny and Lower Conemaugh to the top of the Saltsburg sandstone above the Bakerstown coal and the Upper Group (Surface Mining Province 3) includes the remainder of the section (Lower Conemaugh, Monongahela, and Dunkard) or the beds to the end of the Appalachian (Paleozoic) deposition.

The beds of the lower group (Surface Mining Province 2) are a series of alternating gray shale and sandstone (Pottsville 36 to 86 percent; Allegheny 4 to 48 percent; and Lower Conemaugh up to 60 percent). Fresh-water limestone and marine shale were deposited only in the northern most reaches of West Virginia until marine incursions deposited limestone and shale farther to the southwest during Brush Creek and Cambridge time (lower Conemaugh). Marine incursions continued into the upper group with the deposition of the Ames limestone and shale above the Harlem coal (upper Conemaugh), the last recorded incursion of the sea in the Appalachian regions. Flint refractory grade clays up to several feet thick and associated coals, reflecting a relatively stable depositional basin, are confined to beds of the lower group in Hancock, Taylor, Preston, Mineral and Randolph Counties.

Coals are thin, poorly developed, absent, or of small areal extent in the lower group in West Virginia with the exception of the somewhat irregular Kittannings (3), Freeports (2), Mahoning, Brush Creek, and Bakerstowns (2) in Surface Mining Province 2 which nearly coincides with the Allegheny Mountain Section plus contiguous areas short distances to the west. Of the 10 named coals, 9 are considered to be commercial coals locally and all are amenable to surface mining at some place in the Province.

Structural activity in the Allegheny Mountain Section resulted in a series of en echelon folds (upwarps and downwarps) trending to the northeast. It is believed that deformation was active during the deposition of the beds resulting in a garbled sequence of locally developed coals and associated sandstones, located near the surface of synclines (downwarps) and conversely thinning or eroded over the anticlines (upwarps). The changeable characteristics, including thickness, and sulphur content (high or low) of the bituminous coals (volatile matter 32 to 36 percent) and associated rocks of Surface Mining Province 2 reflect the complexity of the depositional and structural history of the Allegheny Mountain Section.

In addition to the larger area of Surface Mining Province 2, beds of the lower group are exposed along the Burning Springs anticline, a sharp narrow, north-south trending structure, in Pleasant County and in the northern extremities of the Northern Panhandle (Hancock County), West Virginia (Figure 1). Surface mining of the Upper Freeport has been conducted at the former and surface mining of the Lower Freeport clay and coal and the Mahoning coal has been conducted at the latter site. The coals are relatively thin and the areas involved are small. No further mention of the lower group of rocks in these areas will be made in connection with Surface Mining Province 2 here.

The beds of the upper group (Surface Mining Province 3) (upper Conemaugh, 550 feet (165 meters); Monongahela, 450 feet (135 meters); and Dunkard, 1180 feet (360 meters) have a composite thickness of over 2200 feet (660 meters). The facies relationship depicts a series of alternating red and gray shales intercalated with sandstone, coal, clay-shale and fresh-water limestone shifting alternately back and forth in time from northeast to southwest. Northward, the beds of a given section are entirely gray or predominantly so, consisting of clusters of mudstone (shale), clay-shale, fresh-water limestone, coal, roof shale, and thin- to massive-bedded sandstone (up to 15 percent) in ascending order; this is the lacustrine-swamp or gray facies (Arkle, 1959) which contains the principal development of coals in Surface Mining Province 3. To the southwest of the gray facies development, the section loses limestones first and then coal. Gray shale intertongues with dusky red and yellow shale and the sandstones become more massive and tend to coalesce vertically with other sandstones attaining thicknesses of as much as 100 feet (up to 37 percent of the section); this is transitional facies. Localized surface mining areas in Province 3 in central and southwestern West Virginia are generalizations of locations of usually only one prospective and not more than two coals in the transitional facies development. Farther to the southwest, these units grade laterally into dusky red and yellow shale alternating with argillaceous massive- to thin-bedded sandstone containing pebbly zones (more than 30 percent of the section); this is the alluvial or red facies. The large area adjacent to the surface mining limits of Surface Mining Province 3 and barren of prospective mineable coals in central and southwestern West Virginia is attributed to the development of red facies.

Of the 37 named bituminous coals in the upper group, only 10 are considered to be mineable. In ascending the section, the Harlem, Elk Lick and Little Pittsburgh coals are only commercially mineable locally high in the hills of Surface Mining Province 2. The Pittsburgh, a remarkable stratigraphic marker, is the principal coal of northern West Virginia and Surface Mining Province 3 and is responsible for about 25 percent of the annual coal production of West Virginia. It has been largely removed by underground and surface methods of mining in areas of local distribution in high areas of Preston and Mineral Counties of Surface Mining Province 2. In addition to the Pittsburgh, the Redstone, Sewickley, Uniontown, Waynesburg, Waynesburg "A", and Washington in ascending 550 feet of section are prospective coals locally for surface mining along the Ohio and Monongahela Rivers and their tributaries. The coals all occur below drainage in tributaries east of the Ohio River and west of the Monongahela River in the Dunkard Basin (Figure 1) a broad synclinorium exposing the youngest rocks of the Appalachians in Wetzel, Marshall, Ohio, and Monongalia Counties in West Virginia. The Jollytown, Dunkard, Fish Creek, Hostetler, Nineveh Gilmore and Windy Gap Coals, all thin and impure, are locally distributed along the axis of the Dunkard Basin.

The coals of Surface Mining Province 3 are considered to be high-sulphur, i.e., greater than 1.50 percent, and high volatile, i.e., 32 to 36 percent coals. The volatile matter and sulfur content of coals of the upper group, viz., the Little Pittsburgh, Pittsburgh, Redstone, and Sewickley, decrease to the east on limited exposures, mostly mined, high in the hills of Surface Mining Province 2.

Geology of the Pennsylvanian System of Preston County

The land forms of Preston County are the result of complex forces that have acted through successive periods of the geologic past. The major anticlines (Figure 2), the Chestnut Ridge on the west and the Briery Mountain in east central Preston County were folded exposing resistant sandstones of Pottsville age (generally with thin non-commercial coals) (Figure 3), which form conspicuous northeast trending linear land forms of Chestnut Ridge, Laurel Ridge, Brushy Knobs, Snaggy Mountain, and Backbone Mountain. The area of principal study is between the two major structures where less intensely folded structures expose younger, less resistant rocks of the Allegheny, Conemaugh and basal Monongahela Groups. The regional relief of Preston County is 2200+ feet. The elevation rises from 800 feet (240 meters) A.T. along the Cheat River in the northwest to an elevation in excess of 3300 feet (990 meters) A.T. on Backbone Mountain in the southeast corner of Preston County.

Subsequently, the Cheat River of the Monongahela River Drainage dissected the upland plateau and developed deeply entrenched valleys. The streams have beveled local base levels, forming pleasant glades on massive sandstones. These same sandstones when exposed above drainage support steep-walled valleys. Steep hillslopes, exposing series of underclays or locally developed fresh-water limestones, thin to thick irregular coals, two zones of marine shale, locally thin limestone, the Brush Creek and Ames above the Brush Creek and Harlem coals, respectively, gray shale, and thin- to massive-bedded sandstones, rise from the stream bottoms to pleasant rolling upland areas, generally

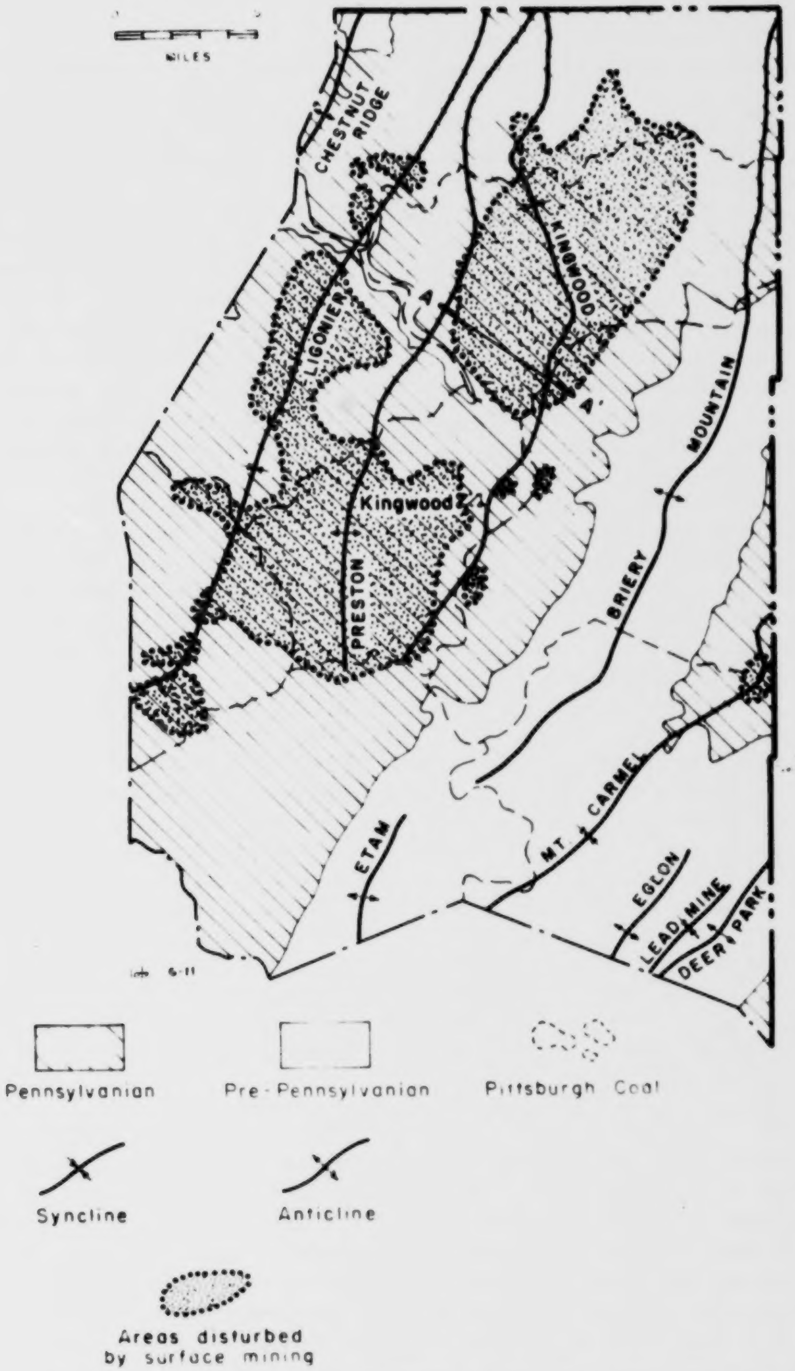
MILES
CHESTNUT RIDGE
LIGONIER
A
KINGWOOD
A'
Kingwood
PRESTON
BRIERY
MOUNTAIN
MT. CARMEL
ETAM
EGLON
LEAD MINE
DEER PARK
Pennsylvanian
Pre-Pennsylvanian
Pittsburgh Coal
Syncline
Anticline
Areas disturbed by surface mining

FIGURE 2. GEOLOGIC STRUCTURE AND PRINCIPAL AREAS OF MINING IN PRESTON COUNTY

underlain by massive sandstone, which supports a farming culture.

Figure 2 generalizes the areas disturbed by surface mining of several coals, viz., the Lower Kittanning, Upper Kittanning, Lower Freeport, Upper Freeport, the Mahoning and Brush Creek, locally Bakerstown, Harlem and Pittsburgh coals. The Upper Freeport coal contributed most importantly to coal production by underground mining methods since mining commenced in about 1888. Locally, the Bakerstown coal has been of secondary importance in the production of coal by underground mining methods. Two coals, the Lower Kittanning near Newburg and the Pittsburgh at Scotch Hill have been mined extensively by underground methods in areas of local development and local exposure (Figure 2), respectively. All of the coals listed above have been mined in small drift mines in the past (for household purposes). Relatively small areas (included within the larger area disturbed by surface mining) have been mined by underground mining methods and relatively few areas of coal (perhaps 2 square miles), having adequate overburden and suitable thickness and physical and chemical characteristics, are known to exist in Preston County. Geological considerations, including fairly intense inclinations of the rocks and large areas of "no coal," as well as high labor costs make the development and amortization of even small fixed plants (100,000 to 500,000 tons annually) difficult, and limit the productivity, particularly at the present time. Conversely, the larger area underlain with as many as 9 coals with varying amounts of overburden, thickness, and physical and chemical characteristics can be mined more efficiently by methods of surface mining because of the higher productivity and lower cost of amortization of highly mobile equipment. For example, local developments of the Upper Kittanning and Lower Freeport above drainage, both marginal coals, have been mined in conjunction with surface mining of the Upper Freeport coal, an interval of about 100 feet, in the Bruceton Mills-Brandonville area of Preston County. The Mahoning and the Brush Creek coals are only locally of marginal mineable thickness above the Upper Freeport or below the Bakerstown coals (the interval in either case is about 100 feet, 30 meters), and the Harlem and Pittsburgh coals, interval 260 feet (78 meters), are only locally available high in the hills of Preston County.

Mining of coal by surface methods in Preston County commenced with the advent of World War II. The production of coal by surface methods was about 200,000 tons annually in 1950. The coal-burning Albright Power Station was completed at Albright by the Allegheny Power System in the middle 1950's. The production of coal by methods of surface mining, disturbing a large area of the land surface in Preston County, has increased several times in the intervening years (Appendix C).

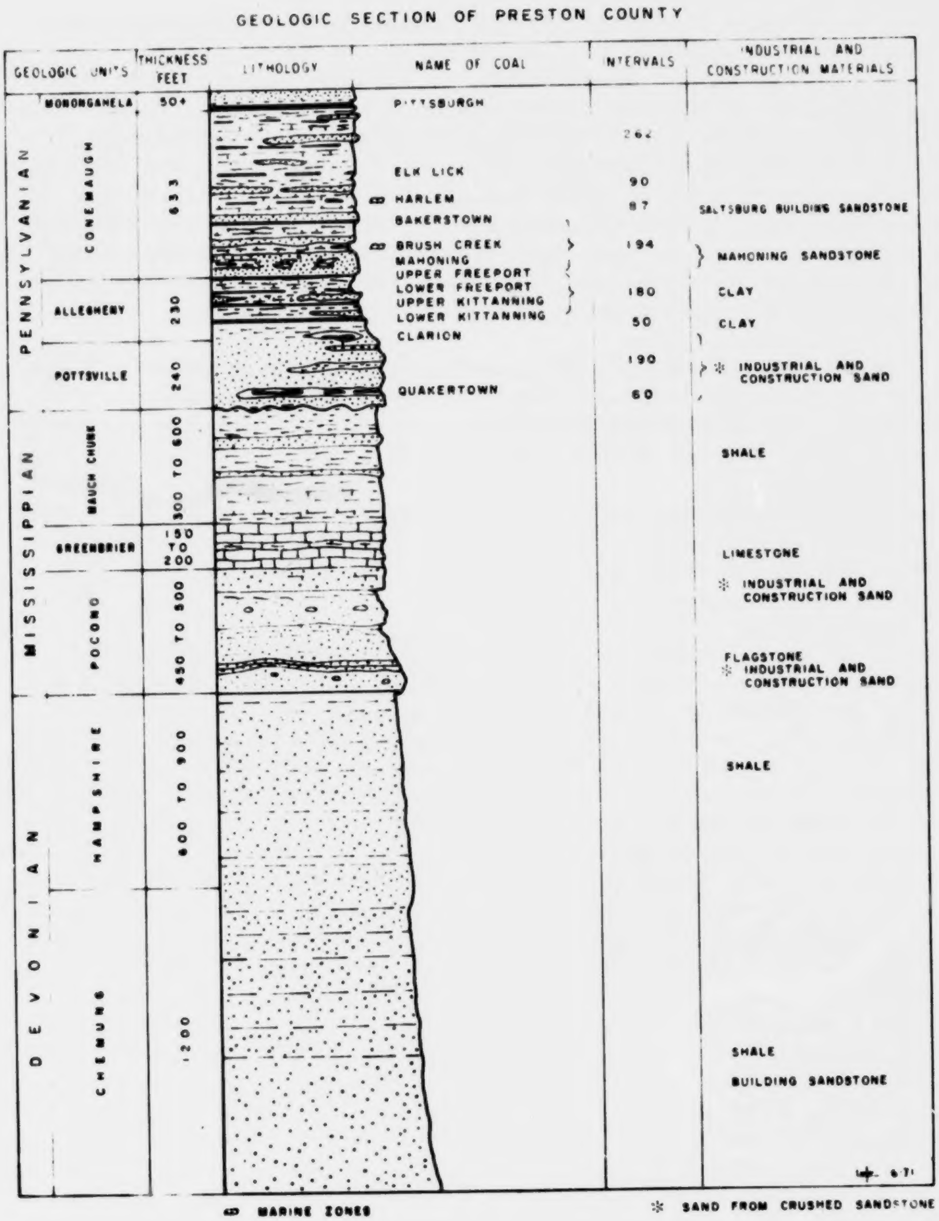
GEOLOGIC SECTION OF PRESTON COUNTY
GEOLOGIC UNITS
THICKNESS FEET
LITHOLOGY
NAME OF COAL
INTERVALS
INDUSTRIAL AND CONSTRUCTION MATERIALS
PENNSYLVANIAN
MONONGAHELA
50+
PITTSBURGH
CONEMAUGH
633
262
ELK LICK
90
HARLEM
87
SALTSBURG BUILDING SANDSTONE
BAKERSTOWN
BRUSH CREEK
194
MAHONING
MAHONING SANDSTONE
UPPER FREEPORT
ALLEGHENY
230
LOWER FREEPORT
180
CLAY
UPPER KITTANNING
LOWER KITTANNING
50
CLAY
CLARION
POTTSVILLE
240
190
INDUSTRIAL AND CONSTRUCTION SAND
QUAKERTOWN
60
MISSISSIPPIAN
MAUCH CHUNK
300 TO 600
SHALE
GREENBRIER
150 TO 200
LIMESTONE
POCONO
450 TO 500
INDUSTRIAL AND CONSTRUCTION SAND
FLAGSTONE
INDUSTRIAL AND CONSTRUCTION SAND
DEVONIAN
HAMPSHIRE
600 TO 900
SHALE
CHEMUNG
1200
SHALE
BUILDING SANDSTONE
6-71
MARINE ZONES
SAND FROM CRUSHED SANDSTONE

FIGURE 3. GEOLOGIC SECTION OF PRESTON COUNTY

Robert V. Hidalgo (1969, p. 309-320) investigated the sulphur-clay mineral relationships at two locations of the Upper Freeport coal in Preston County; Robert Cheek (1969, p. 279-304) investigated the sulphur facies of the Upper Freeport coal in northwest Preston County; and Walter B. Ayres, Jr. (1970, p. 10) interpreted the geology of the section (Figure 4) between the Upper Freeport coal and Saltsburg sandstone in the area of principal study. Although much of the analytical data is confined principally to the sulfur distribution in the Upper Freeport coal, the interpretations may be applicable to the study of spoil material. The findings of these investigations are included with comments in the following paragraphs.

An enumeration of some of the primary, penecontemporaneous and subsequent structural features, imposed during the deposition of the sediments or superimposed secondarily at a later time are discussed although they are not clearly understood.

The detrital minerals, i.e., the transported minerals or those derived from pre-existing rocks, are principally quartz and clay minerals, some feldspar and minor quantities of a suite of ubiquitous fine-grained heavy minerals.

Natural zones of weakness, present along horizontal bedding and angular cross laminations of layered rocks, and the granular sediments, are initially porous. The primary porosity is altered subsequently with the introduction secondarily of alteration products such as clay and micaceous minerals, quartz, carbonates (calcite and siderite), iron (hematitie, limonite, and pyrite) and manganese. The lack of cementation or the filling of interstices of granular material is measured by the permeability, i.e., the ability of a substance to transmit a fluid. Sandstones, the most permeable rocks of Preston County, are altered by the degree of cementation. Zones of weakness were imposed during deposition by readjustments called block slumping and during the transformation to consolidated rock by structural adjustments called slickensides, usually prevalent in the shales. Finally, sets of joints, called cleats in coal, usually nearly at right angles to the bedding, were developed during the folding of the Appalachian Mountains. It is in this complex system of varying porosities, slump blocks, slickensides and joint sets that the authigenic minerals, i.e., minerals formed in the place of occurrence, were formed. Authigenic minerals are formed in several different ways. Some are precipitated from solution in water at the same time that the sediment is being deposited; others are formed by the action of pressure and solution in the pores and adjacent areas of granular rocks at a considerable distance below the surface; and others are the result of surface weathering of minerals which may be either detrital or authigenic.

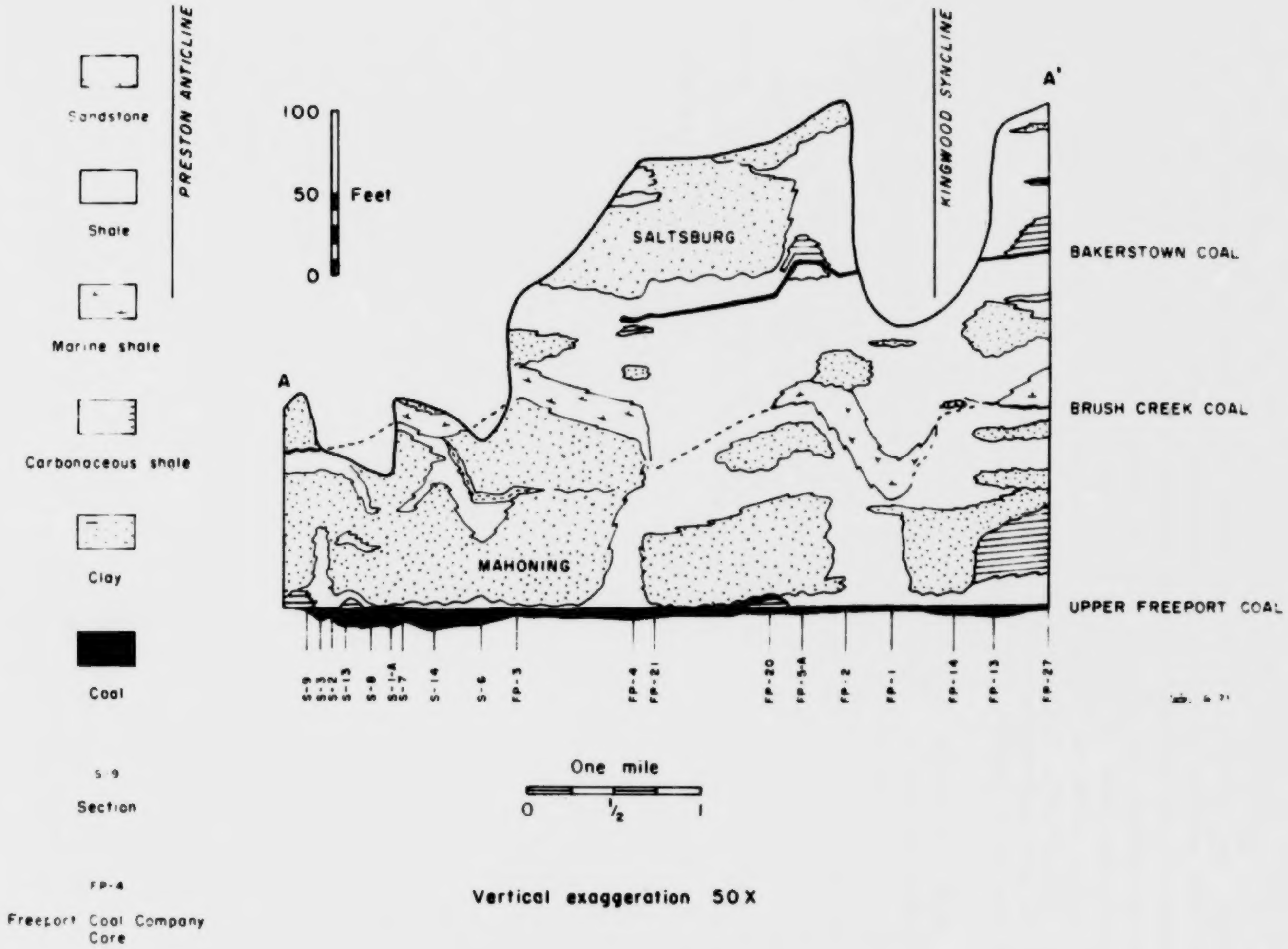
Sandstone
Shale
Marine shale
Carbonaceous shale
Clay
Coal
S-9
Section
FP-4
Freeport Coal Company Core
PRESTON ANTICLINE
KINGWOOD SYNCLINE
100
50
0
Feet
A
A'
SALTSBURG
MAHONING
BAKERSTOWN COAL
BRUSH CREEK COAL
UPPER FREEPORT COAL
S-9
S-3
S-2
S-13
S-8
S-1-A
S-7
S-14
S-6
FP-3
FP-4
FP-21
FP-20
FP-5-A
FP-2
FP-1
FP-14
FP-13
FP-27
One mile
0
½
1
Vertical exaggeration 50X

FIGURE 4. CROSS SECTION SHOWING VARIABILITY OF BEDS BETWEEN UPPER FREEPORT COAL AND SALTSBURG SANDSTONE

Authigenic minerals recognized by the field geologist in West Virginia are iron minerals, viz., hematite (iron oxide), limonite (hydrous iron oxide), and pyrite (iron disulphide) and manganese minerals and the alkaline earths, principally carbonates, calcite (calcium carbonate), dolomite (calcium magnesium carbonate) and siderite (iron carbonate). The carbonates are disseminated in pores, as cement in granular rocks and concentrated along zones of weakness, viz., joints, slickensides, and other zones of weakness, as limestone and siderite lenses, nodules, and concretions, particularly in shale. The net result of the weathering of the carbonates is to buffer, to inhibit and finally to neutralize the acid forming components of the associated rocks.

The most important acid-forming mineral in the section is pyrite, less commonly marcasite. Pyrite occurs in practically all of the rocks including coal and associated rocks represented in unweathered samples in West Virginia except for those that are red in color, containing hematite or iron oxide formed in an oxidizing environment. It is generally more plentiful in the dark to black rocks (carbonaceous shale to bone coal in the Coal Measures) than those that are light gray to grayish green. Pyrite occurs as coatings and shales in pores, interstitial materials, and along zones of weakness and is finely disseminated as cubes and in combination with numerous other complex geometric forms. Pyrite was formed in place (authigenic) and is an indicator of reducing conditions often in the presence of organic matter. A considerable number of samples contain pyrite fragments with carbon attached and have structures which indicate replacement of plant remains (the organic sulfur component) by the pyrite (Martens, 1939, p. 16).

Headlee (1955, p. 23-35) sampled and analyzed the total, pyritic, organic (selected) and sulfate (limited) sulfur in 3-inch (7.6 cm) increments across the face of the Upper Freeport (59 inches, 150 cm, thick) and Bakerstown (37 inches, 94 cm, thick) coals of Preston County as a part of a larger study of the characteristics of the mineable coals in West Virginia. Averages, or the total, pyritic, organic and sulfate sulfur of all small samples for the Upper Freeport coal were 0.90, 0.44, 0.44 and 0.04 percent and for the Bakerstown were 1.75, 1.24, 0.60 and 0.01 percent, respectively. He observed the great lateral and vertical variations in the pyritic sulfur and the small variations in the organic sulfur of the coals of West Virginia.

Cheek (1969, p. 270) observed (1) that sulphur content of the Upper Freeport coal decreases as the thickness of the coal increases; (2) that the sulphur is higher in bone coal than in coal at the top and bottom of the coal seam; and (3) that the sulphur is higher in coal with a sandstone roof than coal with a shale roof. He further concluded that high sulphur reflects a swamp with good water circulation unimpeded by a dense and intense vegetation. He presumed that the primary pyrite formed in the presence of sulfate and iron bacteria in the coal swamp, whereas the organic sulphur was incorporated in proteinaceous cells in plants during their growth. Later, secondary pyrite was introduced into the coal along fractures and cleats from porous and permeable rocks of the overburden, principally sandstone.

Of the three common clay minerals, illite (mica), kaolinite, and montmorillonite, illite, a potassium aluminum silicate, is the prevalent clay mineral in the shales associated with coals of Preston County. Hidalgo (1969, p. 309) proposed a possible trend of increasing illite and decreasing kaolinite with increasing sulphur in samples of the Upper Freeport coal having greater than 1 percent sulfur. The pyrite formation is dependent on sulfide availability at the time of formation, more so than on iron availability. The iron organic complexes are concentrated in the clay colloid detrital fraction and are preferentially oriented according to sizes favoring illite.

Cross section A-A' (Ayres, 1970, p. 10) (Figure 4) illustrates the relationships of the various lithologies and the lithologies and the complexity of depositional environments during sedimentation from the beginning of the Upper Freeport swamp to the end of the alluviation of the sand which subsequently became the Saltsburg sandstone.

Gross aspects of the cross section show lateral variations in thickness of coals (Upper Freeport, Brush Creek and Bakerstown) from very thick to complete disappearance of all coals laterally. Most mineable coals tend to have higher ash and sulphur contents and other impurities concentrated at the bottom and top, reflecting the abatement and commencement of detritus after the beginning and at the close of swamp development, as well as influences of secondary additions of sulfur at the top of the coal and along zones of weakness within the coal. The average of 42 samples (A.R.) of the mining section of the Upper Freeport coal shows 8.40 percent ash and 1.69 percent sulphur in Preston County; the average of 8 samples (A.R.) of the Bakerstown coal shows 6.75 percent ash and 2.00 percent sulphur (Hennen, et al., 1914, p. 364-366).

The remainder of the section is fine clastics (detrital) essentially clay, micaceous minerals and quartz, forming gray, slightly calcareous shale above the Brush Creek coal, to local developments of darker and carbonaceous shale. Thick lenticular bodies of medium-grained sandstone, ranging from highly argillaceous to nearly quartzose sandstone locally, are superimposed on the shales. The detrital mineral feldspar is present in small percentages in the sandstone in all stages of disintegration. There was probably more feldspar originally, but it has been altered to kaolinite, sericite and other hydrous silicates.

Locally, the cross section shows that surface mining of the Upper Freeport-Bakerstown coals, in intervals of about 200 feet, if economically feasible, would produce a highwall composed principally of shale. Generally, the cross section indicates that a higher percentage of spoils would be composed of shale in a surface mine in Bakerstown coal than in the Upper Freeport coal while conversely a higher percentage of sandstone would compose the spoils of a surface mine in the Upper Freeport. Field studies of highwalls of surface mines in Preston County substantiate the observation of the cross section. In the case of the surface mines in the Upper Freeport coal, the Mahoning sandstone is either directly above the coal or is separated by a thin section of shale from the coal while in the case of the surface mines in the Bakerstown coal, a thick section of shale separates the Saltsburg sandstone from the coal.

The analyses of data from highwalls, spoil banks and cores in the following pages considers approaches to the reclamation of spoils from the surface mining of the various seams of coal in Preston County and adjacent areas.

SECTION V

SOIL CONSIDERATIONS

General (West Virginia)

Since surface mining is substituting mine spoils for pre-existing soils, it is instructive to consider potentials of the mine spoils relative to the standard of natural soils prior to mining.

On a generalized basis, most West Virginia soils in the regions of surface mining have been classified at the Great Group level as Dystrochrepts, Hapludults and Fragiudults (Soil Survey Staff, 1960; U. S. map, 1969). These general categories mean that soil profiles are medium or low in organic matter and are low in basic cations (less than 35% saturated with exchangeable bases at the contact with underlying rock or at 40 inch (100 cm) depths) and that soil profiles vary from slight (Dystrochrepts) to strong (Hapludults and Fragiudults) subsoil differentiation and clay accumulation. Significant areas of Hapludalfs are recognized where subsoil saturation with bases exceeds 35%, constituting the distinction from Hapludults.

Textures, coarse fragments (greater than 2 mm), depths to bedrock, available water capacity, internal profile drainage, surface stoniness, and land slope are other major features that influence natural soil or land quality and its influence on runoff, erosion and water quality.

Any generalization of these properties is likely to be criticized as inadequate or misleading when local or specific cases are considered, but we believe it may be helpful to suggest what we consider to be the most common range within the several soil properties mentioned:

1. Textures - intermediate, i.e., loams, silt loams and clay loams.

2. Coarse fragments - significant, i.e., commonly 25 to 75% of the soil mass by volume, influencing available water capacities proportionally.

3. Depths to bedrock - moderately deep, i.e., 50 to 100 cm (20 to 40 inches) (less on ridgetops and deeper on slopes of colluvium).

4. Available water capacity - medium to low, i.e., 0.08 to 0.12 cm per cm (or inches per inch) of depth, including influence of coarse fragments.

5. Internal profile drainage - moderately limiting, i.e., good to poor, with common impedence by horizontal bedrock or by fragipans or claypans.

6. Surface stoniness - moderate, i.e., surface stones dominate land use on significant areas.

7. Land slope - steep, i.e., significant on most land and dominating land use of the southern region, Surface Mining Province 1. (Figure 1)

Specific (Preston County)

The four Great Groups of soils mentioned under the General discussion were represented at sites studied in Preston County. Representative profiles of three Great Groups were selected for detailed descriptions and sampling. These descriptions are included in Appendices, pp. 182 to 203. Series represented, as indicated in descriptions, were Dekalb, Gilpin, Cookport, Wharton and variants of Dekalb, Cookport and Westmoreland (no profile description). One Dekalb variant was slightly outside the series definition in depth to bedrock (less than 20 inches, 50 cm) and also in having a slight excess of clay in the subsoil (Control section). The Cookport variants were fine silty rather than fine loamy in the subsoil (control section) as required for Cookport. These soils might be considered members of the Tilsit series, but they are not so designated here because this series has not been recognized in Preston County nor at the latitude and elevation represented. Some Westmoreland observed is a variant which has more red color in the subsoil than defined for the series. The Wharton is an upland claypan soil. The series closely resembles the Cookport except it does not have the fragipan as described in the Cookport and Cookport variants. Wharton has somewhat impeded drainage as can be seen from the mottling described in the profile descriptions.

The soils described, except the Westmoreland variant, were found over the Lower Mahoning sandstone, the prominent sandstone overburden of the Upper Freeport coal. Soil differences that account for the different Great Groups and the more detailed series distinctions apparently are traceable to textural and mineralogical variations in the parent rock. Land slope and rock fractures formed by geologic folding may have contributed to genesis of the particular soils represented. Low versus high chroma mottling in Cookport and Cookport variant subsoil and immediately underlying rock has attracted special attention and study because of the marked similarity of the subsoil color contrast at the base of the zone of rock weathering. However, as presented in detail elsewhere (Grube, et al., 1971) the chemical and mineralogical cause of the subsoil mottling was found to be contrary to that at the base of rock weathering.

Details involving soils are presented in following sections. Appendices include morphological descriptions of soil profiles (pp. 182 to 203).

Summary

Soil classification, based on soil profile properties, has been generalized for the West Virginia Surface Mining Provinces as a basis for judging environments before and after surface mining. And on a local basis, specific soil profile properties and classification has been identified which reflect rock characteristics and help explain weathering reaction and water quality to be expected in known sequences of mine spoils.

SECTION VI

METHODS ADAPTED TO MINE SPOILS

The field sampling, laboratory subsampling, and analytical laboratory methods used in studies of coal overburden materials were adapted from standard techniques used by geologists and soil scientists in coal, rock, and soil analysis. Some methods were modified to accommodate particular objectives of this project, and to improve precision and accuracy where no procedures were recognized as singularly applicable to mine spoils.

Samples of rock strata between the soil and a surface mineable coal seam were obtained by collecting expelled material from rotary drilling of blast holes. Cooperation of company drilling crews allowed acquisition of "rock chips" in 32 cm (12.5 inch) increments as drilling proceeded. The rock fragments from each interval were collected on a shovel and then poured into a one-pint, waxed paper, ice cream carton. The drilling equipment normally was located on a bench a few feet below the natural land surface, the soil and highly weathered rock having been removed with a bulldozer. Sampling from the drilling bench up to the adjacent soil surface was done by hand, in graduated increments. The soil profiles were sampled by morphological horizons according to accepted methods (Soil Survey Staff, 1951, 1960). At several sites overburden samples were obtained by hand collection at intervals on a fresh high wall using an extension ladder.

Sulphur

The Leco Induction Furnace with Automatic Sulfur Titrator was used for most sulphur analyses. A 0.5 gram sample was used, except where sulphur was above 1.0%, then 0.1 gram was used. Potassium iodate titrant concentrations of 1.29×10^{-4} M and 5.18×10^{-3} M were used The low concentration was appropriate from 0.000 to 0.025% sulfur in a 0.5 g sample; the more concentrated titrant, from 0.005% to 1.0% sulfur in a 0.5 g sample. In addition, a low-sulfur crucible was used in conjunction with the dilute titrant to increase precision in samples low in total sulfur.

In samples of pulverized sandstone, which constituted the majority of the samples processed, the presence of sulfate was determined qualitatively by testing a water extract with concentrated barium chloride for precipitation of barium sulphate.

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Net Acid or Base Potential

Recognition that rock strata may contain base-rich components (mainly as carbonates), as well as acid-producing compounds, dictated an evaluation of acid-base balances. The procedure used for bases was a modification of that used to measure the neutralization equivalence of agricultural limestone (Jackson, 1958). Thus, the "neutralization potential" of individual samples could readily be measured by comparing the total quantity of basic components with the total quantity of acid that could be expected from oxidation of the pyritic materials in the sample. Calculation assumes that the amount of pure calcium carbonate required to neutralize the sulfuric acid resulting from oxidation of pyrite in a material containing 0.1% sulfur, all pyritic, is 6,250 pounds per thousand tons of material.

Potential Acidity with Peroxide

Pretreatment of sample (if carbonates are present or suspected)

Ten grams (-60 mesh) of each sample should be treated with 0.5N HCl and allowed to set for 12 hours or overnight, followed by washing with distilled and deionized H_2O (3 times with 25 mls of H_2O). Then wash twice with acetone to remove the H_2O and any residual $MgCO_3$. Place the sample in an oven set at 40°C or in a vacuum desicator which contains a desicant such as silica gel until dry.

Procedure

1. Weigh accurately 2.0 gms of sample (-60 mesh) and transfer to a 300 ml tall form beaker.

2. Add 24 mls of (30 to 35%) H_2O_2 to the beaker and place on a hotplate at approximately 40 to 50°C to get the reaction started. As soon as sample starts to react, remove from hotplate and allow reaction to go to completion.

   Initial reaction may be quite turbulent when samples contain 0.1% sulfur or greater.

3. After initial reaction is completed, add 12 mls of H_2O_2 and allow to react, place on hotplate at approximately 90°C for 30 minutes to destroy any excess peroxide in solution that has not reacted.

4. Filter through Whatman No. 42 filter paper into a 250 ml flask and dilute the volume to 100 mls by washing sample with distilled and deionized H_2O. The residue in the filter paper can now be discarded.

5. The 100 mls of solution is now heated to boiling to drive off any dissolved CO_2. The flask is stoppered and allowed to cool to room temperature.

6. The titrant used is 0.01 N NaOH that is free of CO_2 and protected from the atmosphere after it has been prepared and standardized with $KHC_8H_4O_4$.

7. The 100 mls of solution is now titrated to pH 7.0 using a glass electrode pH meter, or Bromothymol Blue, which changes from yellow to blue at pH 6.0 to 7.6, and with experience provides close agreement with meter readings.

8. Calculations - (mls of NaOH) x (Normality of NaOH) x (50) = meq/100 gms.

The stoichiometric reaction of pyrite in an oxidizing environment for generating acidity is: $4FeS_2 + 15O_2 + 14H_2O = 4Fe(OH)_3 + 8H_2SO_4$. This reaction proceeds slowly and in three stages with the first and second stages being the rate determining steps.

(1) $2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4$

(2) $4FeSO_4 + 2H_2SO_4 + O_2 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O$

(3) $Fe(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4$

In nature the reaction may proceed slowly over a long period of time through intermediate steps, depending on activity of microbes, concentration of Fe(111), partial pressure of O_2, and other environmental variables. Attempts have been made in the laboratory to generate acidity by simulating natural weathering. Over time spans of several weeks, the simulated weathering releases only a fraction of the potential acid and is still quite time consuming.

Several attempts were made to utilize strong oxidizing agents such as $KMnO_4$, HNO_3, $K_2Cr_2O_7$ and H_2O_2 to oxidize the pyrite in spoil materials. Preliminary results indicated that to get a titratable measure of acidity, using a standard base as the titrant, only the H_2O_2 might be satisfactory.

The first experiment with three replicates of each rock type, indicated that it was feasible to use H_2O_2 to oxidize certain rock materials and get a measure of resulting acidity (Table 1). The rocks were weathered Mahoning sandstone (high chroma sandstone), unweathered Mahoning sandstone (low chroma sandstone), and Uffington shale (low chroma shale). Amount of acidity was calculated using the stoichiometry mentioned. Efficiency of the H_2O_2 oxidation of the sulfur for the three different types of material varied most between replications of high chroma sandstone samples which contained the lowest amount of sulfur.

The data in Table 2 (obtained by the procedure given early in this section, with 9 replicates of each rock type) indicate that the H_2O_2 procedure does give a measure of the amount of acidity that can be produced by these rock samples. For the low chroma sandstone and low chroma shale samples, the replicate efficiencies ranged only from 83.6% to 86.2%. However, for the high chroma sandstone the efficiency ranged from 22.0% to 94.5%.

Theoretical acidity (62 meq x Difference in total sulphur) agrees generally with the actual acidity that was found by titration. For the low chroma shale, some discrepancies may be caused by interactions with clay minerals.

Linear correlation and regression was run using percent total sulphur (before) as the independent variable and the actual titratable acidity in meq H/100 gm as the dependent variable. There was a close agreement between the two and the relationship is shown in Figure 5.

The reactions depicting the oxidation of FeS_2 to H_2SO_4 were the same for the H_2O_2 procedure as those previously shown; however, when using H_2O_2 as the oxidizing agent, there was an excess of O_2 and the rate determining steps proceeded rapidly. The entire reaction was completed in less than an hour.

Lime Requirement

An experiment was designed to investigate the relationship of the soiltest method with direct titration of the spoil material with $Ca(OH)_2$. Sixty-two samples were taken from 13 different spoils in Preston and Monongalia counties area. The samples were air dried and ground to pass a 2 mm sieve. Then they were split, using a stainless steel riffle. Half of the material was sampled and sent to the soil testing laboratory while the other half of the spoil material was sampled for the $Ca(OH)_2$ method.

Table 1

Sulphur in three different rock types, before and after treatment with concentrated H_2O_2.

Sample	% Total Sulfur Before	 After	 Difference	Efficiency %	meq H^+/100 gm Theoretical	 Actual
High chroma sandstone	0.008	0.0015	0.0065	75.0	0.372	-0.69
Low chroma sandstone	0.673	0.158	0.515	76.5	31.93	29.15
Low chroma shale	0.493	0.157	0.336	68.1	20.83	22.88

Note: Determinations made by preliminary methods.

Table 2

Sulphur in three different rock types, before and after treatment with concentrated H_2O_2 and washing to remove sulphates.

Sample	% Total Sulfur Before	 After	 Difference	Efficiency %	meq H^+/100 gm Theoretical	 Actual
High chroma sandstone	0.005	0.0025	0.0029	58.0	0.18	-0.02
Low chroma sandstone	0.647	0.095	0.552	85.3	34.2	32.5
Low chroma shale	0.965	0.144	0.822	85.2	50.9	44.4

Note: Final method as described.

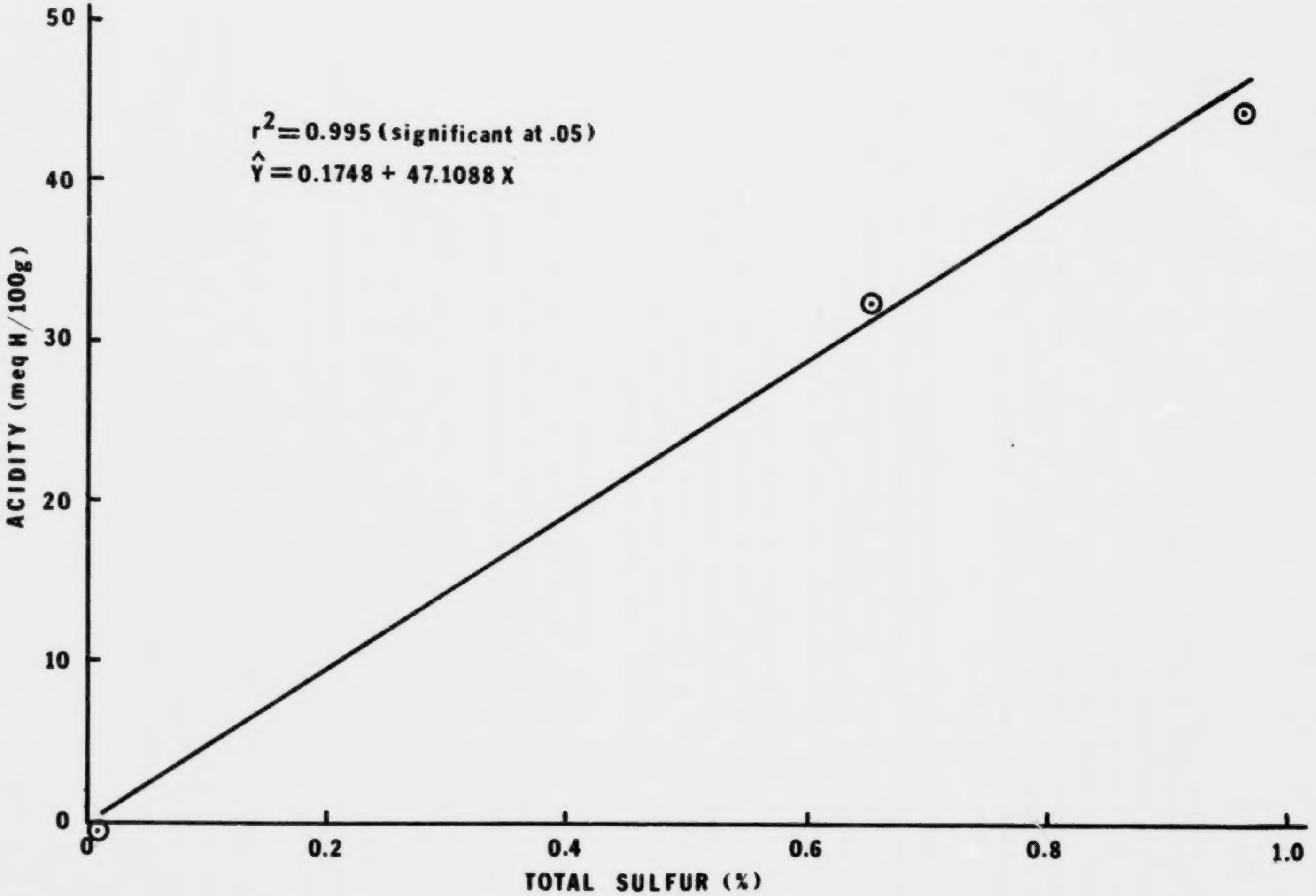

FIGURE 5. RELATIONSHIP BETWEEN MEASURED ACIDITY AND TOTAL SULFUR

The buffer method used in the soil testing laboratory was developed by C. M. Woodruff (Woodruff, 1948). The solution used is calcium acetate buffered by p-nitrophenol. An excess of the buffered solution (at pH 7.0) is added to the sample and allowed to equilibrate for an hour and then the pH of the solution is read and lime requirement is based upon the drop in pH of the buffered solution. By allowing the buffer solution to stand in contact with the sample, Ca^{++} from the solution saturates the exchange complex and H^+ goes into solution, thus lowering the pH.

The method of titration with $Ca(OH)_2$ was developed by L. E. Dunn (Dunn, 1943). The lime-requirement determination is based on titration curves. The 0.04 N $Ca(OH)_2$ is standardized with $KHC_8H_4O_4$ and protected from the atmosphere. Calculations convert the amount of $Ca(OH)_2$(0.04N) directly to tons of lime per acre (2,000,000 lbs).

Each sample was subsampled 7 times and $Ca(OH)_2$ was added at the rates of 1/2, 1, 2, 3, 4, 5, and 6 tons of lime per acre. Then the samples were aerated and incubated for 6 days with the pH being checked daily, following which a titration curve was constructed by plotting pH values on the ordinate and tons of lime per acre on the abscissa. The lime requirement was read from these titration curves.

The effect of this treatment was similar to liming the samples. The exchange complex is saturated with Ca^{++} but unlike the soiltest method the solution is not buffered thus it gives a more direct measure of how much lime will be needed to neutralize the acidity.

Linear correlation and regression was performed using the soiltest data as the independent variable. The peculiar "stacking" of points occurs because soiltest readings are taken in 0.75 ton steps. The correlation was significant at the .001 level and a prediction of the $Ca(OH)_2$ lime requirement can be made with confidence using soiltest readings and the regression equation (Figure 6).

The high "lime requirements" indicated by the buffer method are caused by the empirical correction factor of 1.5 used to compensate for incomplete contact and delayed reaction with pulverized limestone, and perhaps partly by some degree of pyrite oxidation by the NO_2 group attached to the phenol at the paraposition in the buffer solution.

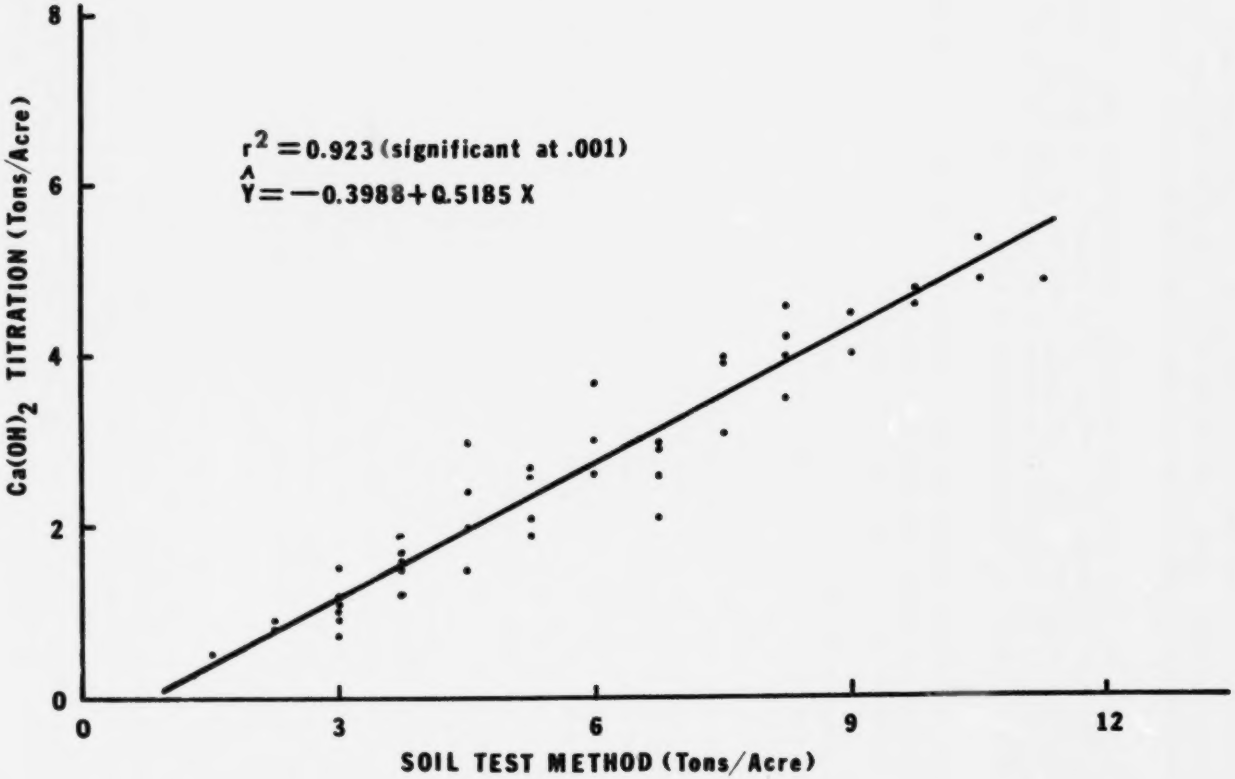

FIGURE 6. COMPARISON OF LIME REQUIREMENTS BY CALCIUM HYDROXIDE TITRATION AND BY SOIL TEST METHODS

Simulated Weathering

1. The humid air method with continuous flow and periodic flushing with water to remove acid, solutes and fine solids, was adapted from the method described by Caruccio (1967).

   This method has demonstrated that unweathered Lower Mahoning sandstone releases titratable acid as well as salts, whereas the weathered sandstone is inert; and underlying dark shales release salts which result from neutralization of sulfuric acid released by pyrite weathering (Section X).

2. The miniature lysimeter or leaching column with interceptor funnels at different depths, with assured *Thiobacillus* inoculation, and periodic water additions to induce leaching.

   This method is being used to determine the influence of depth of burial on rate of acid development from pulverized pyrite (Section XII).

3. Acid Production by Repeated Hot Water Extractions: Several trials were carried out to determine if the Soxhlet extraction technique, used on various biological materials, might have useful application in extraction of acid from coal and coal overburden materials. Pulverized coal or rock was placed in the extraction chamber of the apparatus and distilled and deionized water used as the solvent. Electric hotplates were used to boil the water for 24 hours. The water solution was removed from the apparatus, cooled to 25°C, and pH and titratable acidity or alkalinity were measured using a Fisher Auto Titrimeter. An endpoint of pH 7.0 was reached using 0.200*N* NaOH or 0.200*N* HCl. Except in two samples relatively high in carbonates, the major fraction of acidity or alkalinity, accumulated over a number of successive extractions, was recovered in the first extract. This strongly suggests initial removal of soluble salts, with only small amounts of acidity generated by successive boiling water extractions.

   After six days of extraction, there was little change in acid production, except for the initial large quantity in the first or second treatment, from five Upper Freeport coal samples and seven Lower Mahoning sandstone samples. However, when four of the sandstone samples were carried through twenty-five days of treatments, there was a definite trend toward lower pH in the extract along with gradually increasing release of acidity.

Mine Spoil Classification

In recent years, very little work has been done on strip mine spoil classification. At the present time, West Virginia strip mines are mapped as "strip-mine spoil" (Patton *et al*., 1959) and West Virginia and Pennsylvania strip mine spoils are only classified by properties considered at the lower categories of the soil classification system, according to surface pH, slope and stoniness (Davis, 1965).

Some preliminary work has been done in West Virginia on classification of strip-mine spoils into the present USDA soil classification system (Patton, 1966). However, strip-mine spoils were not classified into the higher categories. Based on the profile descriptions used in this study, strip mine spoils would be classified in the Entisol order. The central concept of Entisols is that of soils that have little or no evidence of development of pedogenic horizons (Soil Survey Staff, 1960). Strip-mine spoils were not classified into any of the other higher categories.

"The purpose of any classification is so to organize our knowledge that the properties of objects may be remembered and their relationships may be understood most easily for a specific objective," (Cline, 1949). Classification assists in short-range and long-range planning and management.

Preliminary classification and testing for revegetation treatments is a temporary expedient which should be followed by long-range classification of the soil for future management and use. Long-range classification and mapping will provide the much needed basis for proper subsequent treatment and management or conversion to specialized uses.

Prompt systematic classification and mapping is especially important because of the following reasons: (1) Mined areas need continued attention and management different from most other land. (2) In many cases, mined land has special potentials because of its slope or soil properties. (3) We have now reached the point in research knowledge, public awareness and extent of mined land that scientific classification for future planned use is necessary. If revegetation and management of strip mine spoils is made easier and more effective, then more land can be put into production and other profitable uses.

An objective of this project is to research the possibility of defining a new suborder and other categories while staying within the boundaries of the comprehensive classification system. Since pH values near the surface vary so much within the first few years, strip-mine spoils that have been revegetated for at least five years are emphasized in this project. As with other soils, it is anticipated that the pH of the top 4 to 8 inches (10 to 20 cm) will not be used as a diagnostic property for classification except perhaps at the phase level. Moreover, the profile "control section" will need to be defined, possibly 10 to 40 inches (25 to 100 cm) within which preliminary information will indicate that pH and related diagnostic properties are stable enough over time to permit a scientific classification to provide a useful basis for use and management to prevent erosion. The control section is defined as arbitrary depths of soil material within which certain diagnostic horizons and other characteristics are used as differentia in the classification of soils. The thickness is specific for each characteristic being considered but may be different for different characteristics.

The suborder "Spolents" is here suggested as a new category to include recently deposited earth materials resulting from surface mining or other earth moving operations, or deposits of solid wastes accumulated with some phase of mining or other industrial activity, or deposits involved in such activities as sanitary landfills. Generally, the earth materials being classified will be vegetated to some degree or will be significantly influenced by microorganisms, but it appears unnecessary to exclude any earth materials because of apparent or assumed absence of biological influences.

The term, "Spolents" is derived from two words. The ending "-ents" comes from the order Entisols. The beginning "Spol-" comes from the Latin spoliare.

The following outline is a proposed classification scheme for strip mine spoil.

(1) Order: Entisols

(2) Suborder: Spolents

(3) Great Groups: a. Udspolents (humid climate)
    b. Uspolents (dry climate)

(4) Subgroup: a. Typic Udspolents (mixed)
    b. Fissile Udspolents (shaly)
    c. Plattic Udspolents (sandstone)
    d. Cubic Udspolents (thick-bedded)

(5) **Family:** Texture, mineralogy, carbonates or acidity, temperature

(6) **Series:**
- a. Profile color
- b. Surface texture
- c. Activity of surface weathering
- d. Inclusions such as coal, nodules, concretions, fossils, limestone

(7) **Phase:**
- a. Slope
- b. Stoniness
- c. Land use
  - (1) Woodland
  - (2) Forages
- d. Surface pH

The adjectives Typic, Fissile, Plattic, and Cubic for the subgroups have only been temporarily defined. After field work has been completed, each category will be defined more precisely.

SECTION VII

FIELD LOCATIONS

Some attention has been given to statewide problems of mine spoil properties and its placement and management. This has involved trips to Kanawha, Boone, Logan, Raleigh and adjoining counties of Surface Mining Province 1 to observe mining operations and results.

In northern West Virginia, we have observed operations involving Pittsburgh and Sewickley coals along the eastern edge of Surface Mining Province 3, and have included some such spoil samples in our laboratory studies, but have done no intensive sampling or study of representative stratigraphic sections.

In Surface Mining Province 2, we have observed operations and reclamation in Tucker, Grant and Mineral Counties as well as throughout central and northern Preston County. However, intensive field studies and sampling have been centered in central Preston County (Figure 7), which appears to typify much of Surface Mining Province 2, as discussed in Section IV. Sampling sites and test cores are readily referred to ground surface points on standard 7 1/2 minute USGS Topographic Maps.

Stratigraphic cross section A - A' (Figure 4) was derived from study of solid test cores, extending as deep as 300 feet. Other test cores studied cover much of the same area as sites A through L (except J), with additional test cores extending southward from G toward the mouth of Muddy Creek at the Cheat River.

Some additional information about sites A through Z is summarized in appendices A and B including detailed soil profile descriptions at several locations.

Summary

Some attention has been given to statewide problems of mine spoil properties and its placement and management, but intensive field study and sampling have been limited to central Preston County, typifying much of Surface Mining Province 2. Within Preston County, coals and overburdens have included the Lower Kittanning, Upper Freeport, Mahoning, Brush Creek, Bakerstown, Harlem and Pittsburgh, with greatest attention centered on the Upper Freeport, because of widespread problems in reclaiming its sandstone overburden, the Lower Mahoning sandstone, throughout Province 2.

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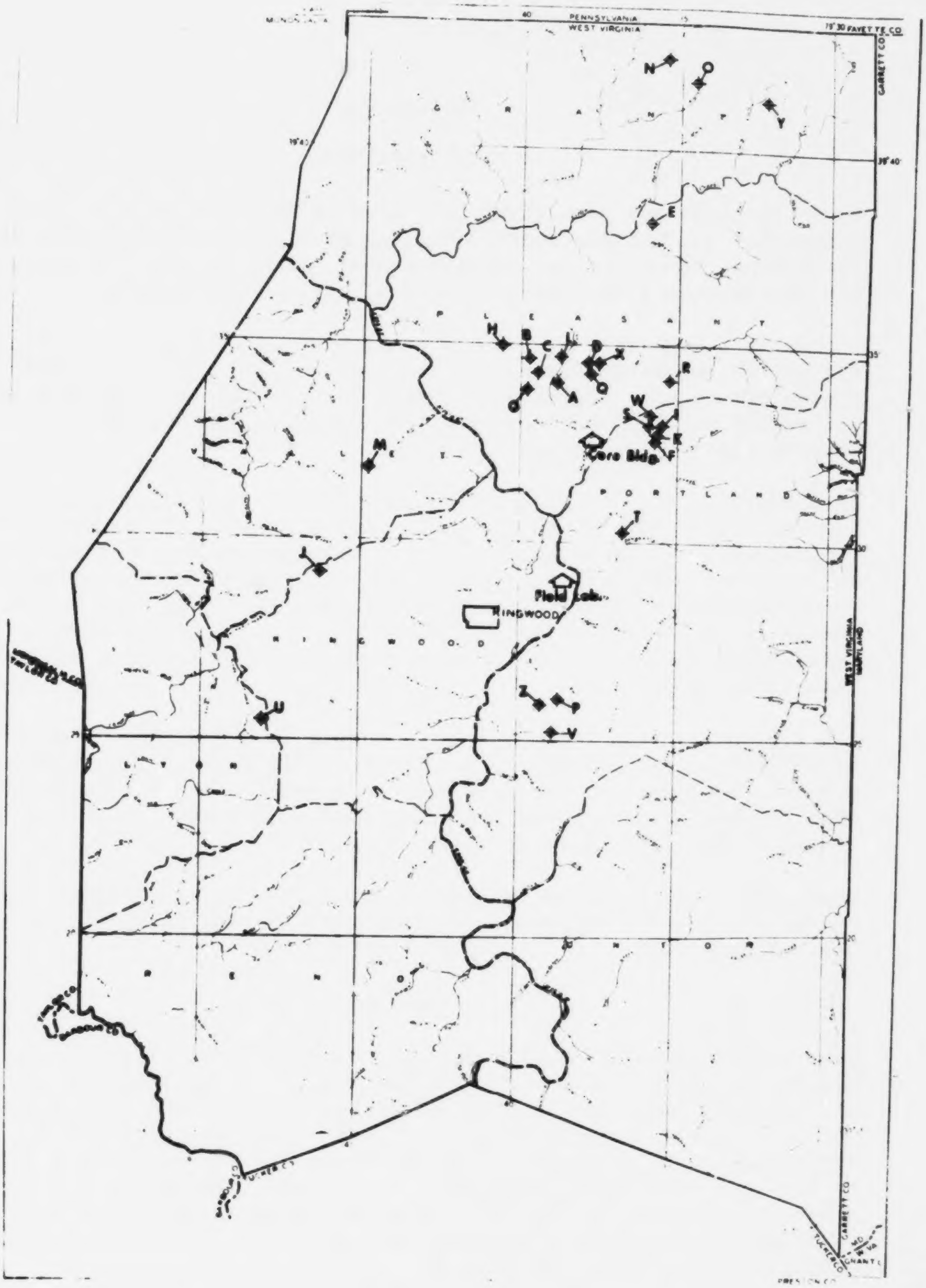
PENNSYLVANIA
WEST VIRGINIA
FAYETTE CO
GARRETT CO
N
O
Y
E
H
B
C
L
D
X
R
Q
A
W
S
K
F
M
Core Bldg
T
J
Field Lab
RINGWOOD
U
Z
P
V
WEST VIRGINIA
MARYLAND
PRESTON CO

FIGURE 7. PRESTON COUNTY SAMPLE AND FIELD STUDY SITES

SECTION VIII

SULFUR AND POTENTIAL ACIDITY

It has been well documented that the oxidation of pyrite is the major concern in considering water pollution and lack of vegetative cover on surface mined lands. Although the quantities and morphological types of pyrite in various coals have been shown to influence the ground water quality (Caruccio, 1967), the scientific literature is barren of quantitative information about pyritic materials in rock strata that constitutes surface mine spoil. The immediate concern of this investigation was to determine the amount of pyrite in rock strata between a strippable coal seam and the land surface. It was assumed that this information would help explain why certain spoils were easily revegetated and produced little acid drainage water, while others were so acid that revegetation was considered impossible. In northern West Virginia, the spoil resulting from surface mining the Upper Freeport seam has been placed in the latter category, therefore, much of the effort of this investigation was aimed toward characterization of the strata overlying the Upper Freeport in this area.

Sulfur Distribution in Overburden Material

Because the relatively humid climate in northeastern U. S. causes intense leaching within the upper few meters at the land surface, it was postulated that sulfate forms of sulfur, being soluble, would approach being negligible in occurrence. Under this assumption, and also the fact that sandstones are low in organic materials except for coal veins, we proceeded with chemical analysis of Upper Freeport overburden rock for total sulfur. Figure 8 illustrates the distribution of total sulfur between the land surface and the Upper Freeport coal at sixteen borings from nine different locations within the Preston County area of investigation. The consistent occurrence of a zone, essentially free of sulfur, penetrating about six meters from the land surface is evident from these data.

Changes in chemical and physical properties of geologic materials due to natural weathering action have long been recognized (Krumbein and Pettijohn, 1966). The depth from the land surface to which these forces penetrate has been shown to range from tens of centimeters in the arctic to hundreds of meters in the tropics (Ollier, 1969). Data obtained in the course of this project indicate a uniform depth range of four to eight meters in northern West Virginia; however, along local fractures oxidized minerals are found to depths of sixteen meters. Except in steep slopes where erosion is severe, the weathered, pyritic sulfur free zone is a bountiful source of spoil material that will not produce significant quantities of acid when exposed as spoil.

The Upper Freeport coal is directly overlain by dark-colored shale, infrequently reaching a few meters thickness in the area of this study. Above this shale, or infrequently directly over the coal, the sandstone, extending to the C horizon of the soils, consists of two zones: the lower, unweathered, dull gray portion; and the upper, weathered zone characterized by the brighter colors of oxidized iron. Reference to Munsell color charts (Soil Survey Staff, 1951) aids consistent characterization of the weathered zone of the rock as "high chroma," and the unweathered zone as "low chroma," many of the samples being of the hue, 10YR. Low chroma, as with soils, refers to chromas of 2 or lower.

The acquisition of several thousand feet of 4.6 cm solid test cores from forty-five boring sites in north central Preston County has allowed us to determine that the Lower Mahoning sandstone is a prominent stratum overlying the Upper Freeport coal in regions not readily exposed as old high walls or current mining operations. Chemical analyses for total sulfur in selected increments throughout this stratum, where one or more overlying sedimentary materials intervene between it and the land surface, show a composition similar to that displayed by unweathered Lower Mahoning obtained during blast hole drilling operations. Figure 9 presents the total sulfur content for several cores where this sandstone was sampled.

The samples from core S-2 were specifically chosen to include black partings, presumed to be small local coal lenses; the greater sulfur content of these sections is apparent. Figure 10 illustrates the changes in sulfur with depth in several predominantly shale overburdens. These data indicate more total sulfur in the weathered zone of these shales than in that of the Lower Mahoning sandstone shown in Figure 8. The Harlem coal seam (Site W) is relatively close to the land surface; this situation emphasizes that low sulfur material is not necessarily always present in near-surface strata. The material represented at Site T is also shale, but varies widely in total sulfur content. The lower four meters of material, lying just over the coal, is high in organic matter and of easily recognizable black color. The composition emphasizes the need to bury this kind of material to prevent pollution problems. The composition of the material overlying the Kittanning seam is shown by Site O, and that the sulfur content is not prohibitive of ready revegetation is borne out by discussion in Section XIII.

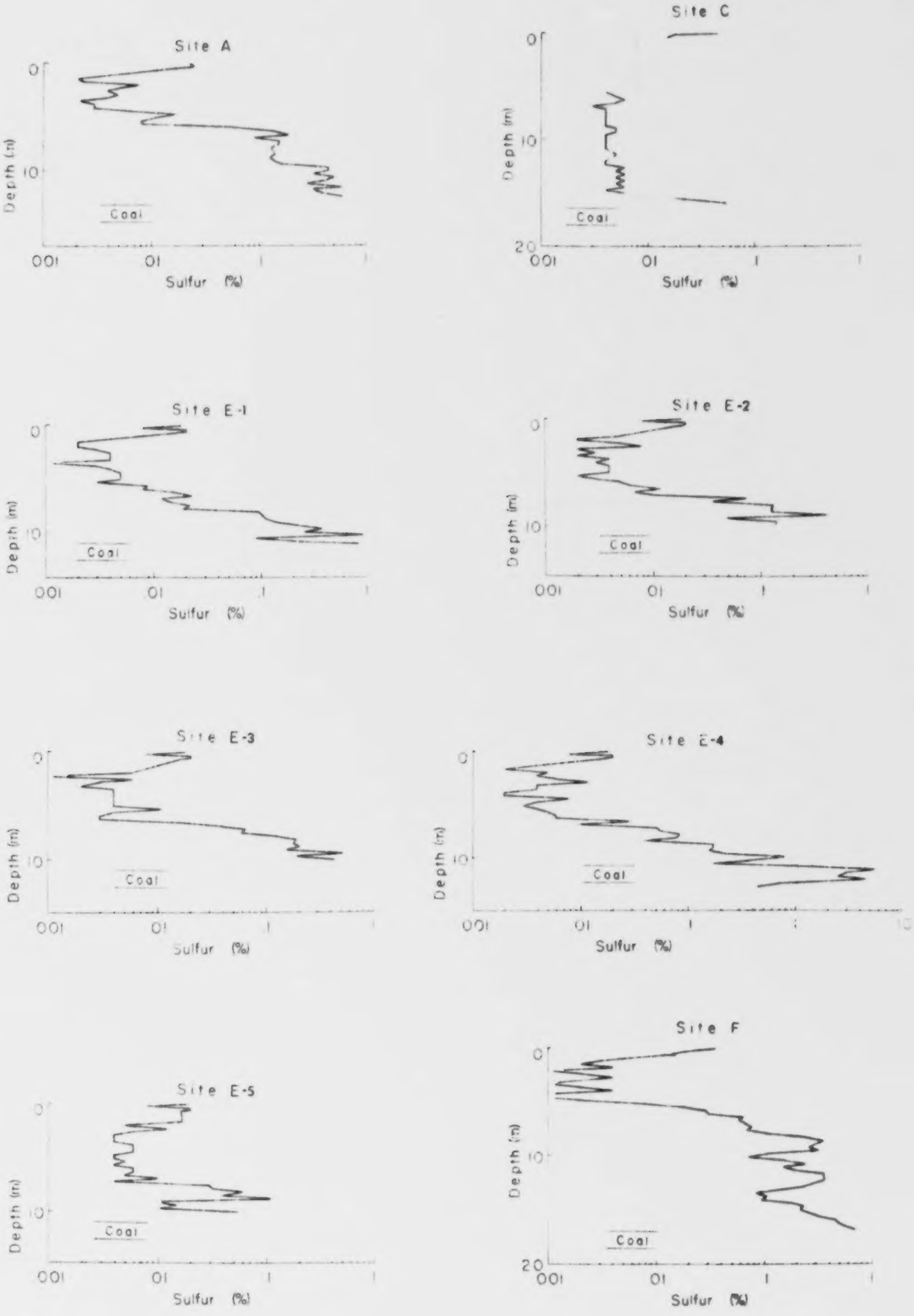

FIGURE 8. TOTAL SULFUR PROFILES IN UPPER FREEPORT OVERBURDEN

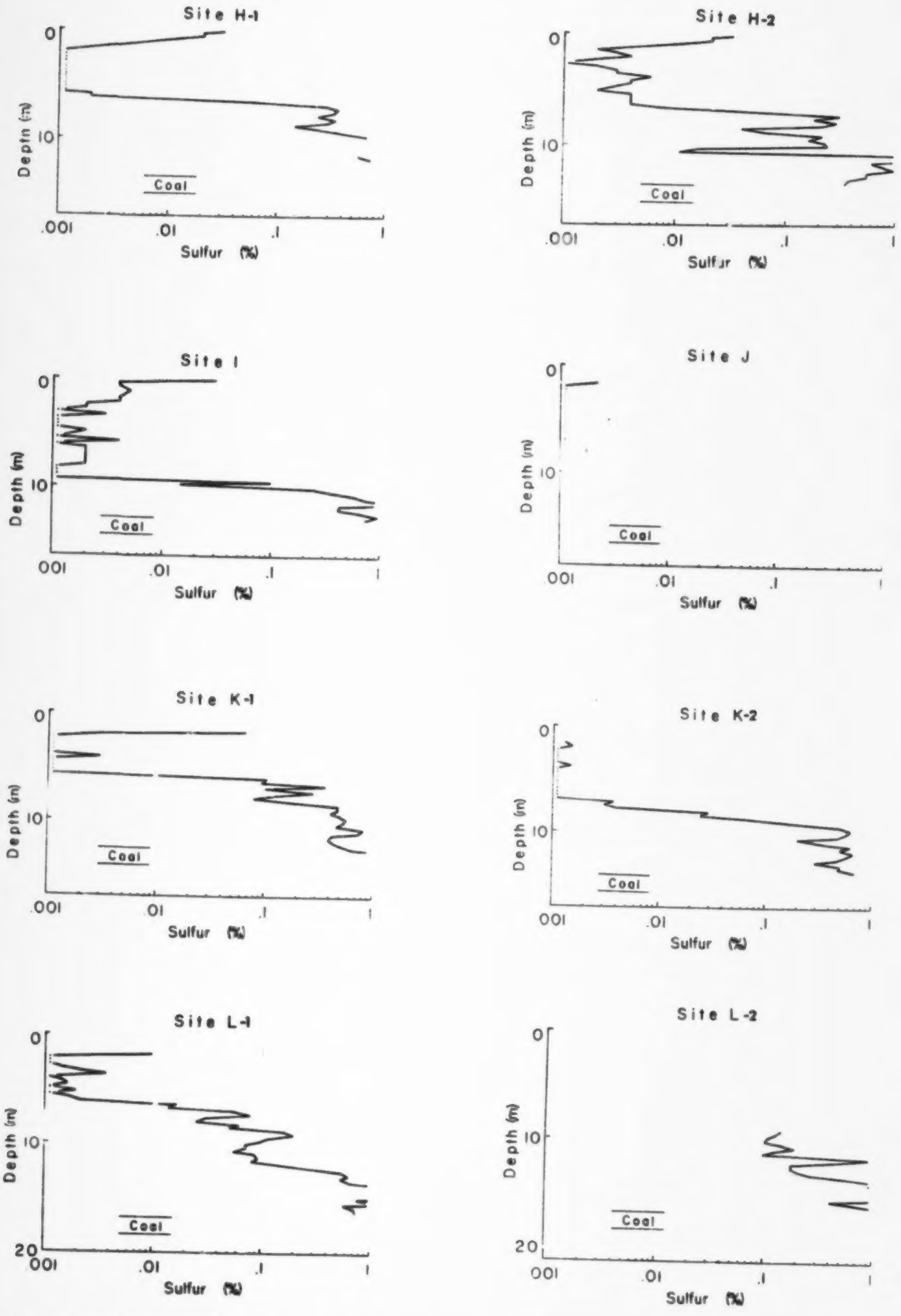

FIGURE 8 (CONTINUED). TOTAL SULFUR PROFILES IN UPPER FREEPORT OVERBURDEN

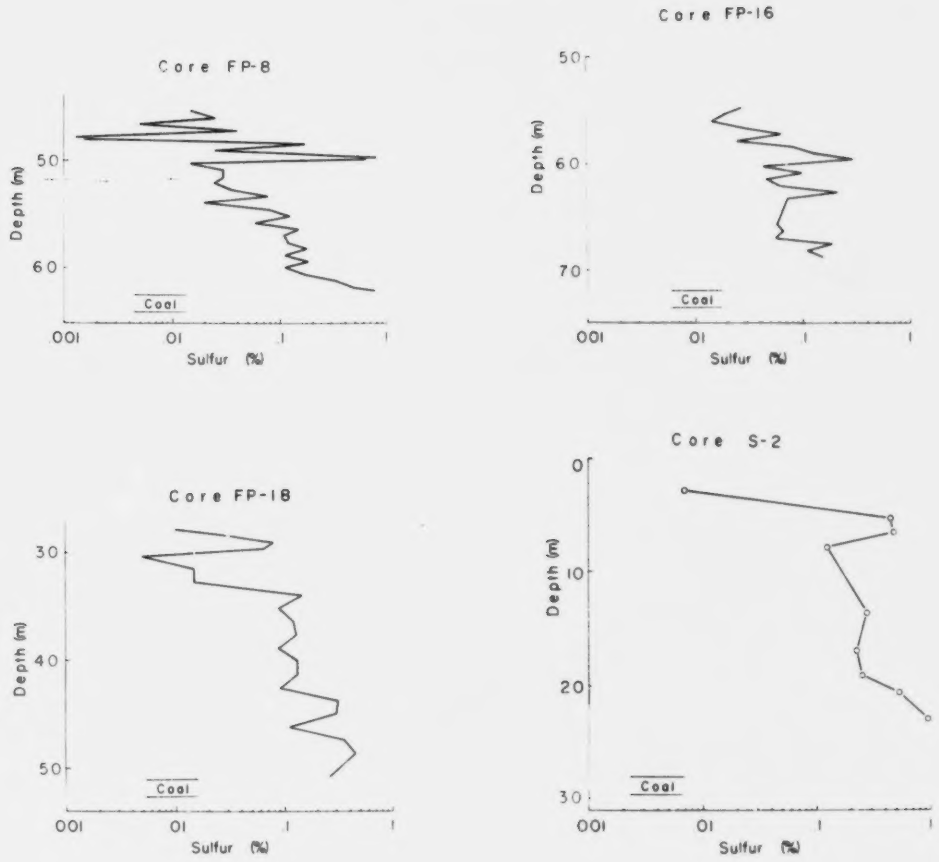

FIGURE 9. TOTAL SULFUR PROFILES IN LOWER MAHONING SANDSTONE UNEXPOSED TO NATURAL WEATHERING

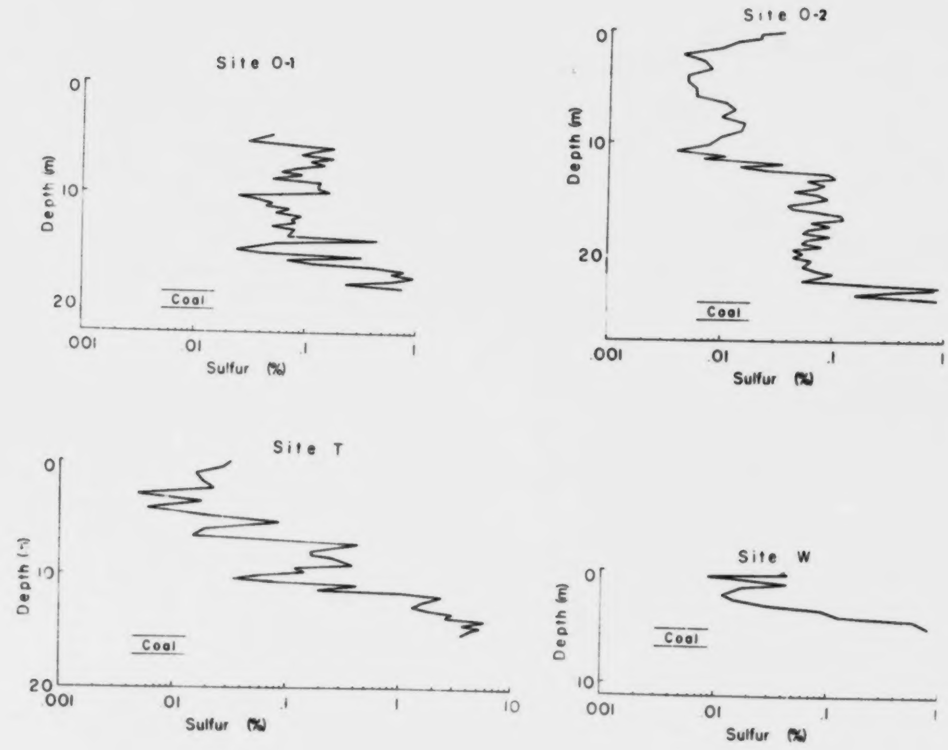

FIGURE 10. TOTAL SULFUR PROFILES IN SELECTED SHALE OVERBURDENS

Petrographic Evidence of Pyrite

Petrographic observations of thin sections indicate that pyrite occurs throughout most rocks buried deeper than about 6 meters below the present land surfaces. Feldspars throughout the sections have altered to kaolinite and (or) dickite or they appear to be in process of such alteration. Persistence of kaolinite from the unoxidized to the oxidized rock and soil zones is apparent. Pyrite, on the other hand, appears relatively stable at depths below about 9 meters, but is sparse or absent in the top 6 meters where segregated hydroxides are prominent. Several modes of occurrence of the pyrite are recognizable and have been distinguished.

Modes of Occurrence of Pyrite and Associated Minerals

Study of thin sections of the acid sandstones indicates that several modes of occurrence of pyrite can be distinguished. These modes include:

1. Euhedral (both single crystals and clusters) pyrite along boundaries between individual sand grains (mostly quartz but some feldspar grains). Some replacement of quartz and feldspars is involved.

2. Euhedral crystals along hairline cracks within individual sand grains. In some cases, the crystals appear to be merely embedded within the grain with no crack evident, but it is assumed cracks were present and some were removed by sectioning. Replacement of quartz or feldspar by pyrite is indicated since crystals are larger than observable hairline cracks. Preferential replacement of feldspars compared to quartz is apparent in some cases.

3. Euhedral crystals disseminated among small (generally silt sized) grains. It seems likely that these crystals are secondary and not detrital although they have not clearly replaced silt grains. Probably they have grown in voids in the original sediment.

4. Crystals (or clusters) with mosaics of secondary kaolinite "books" usually bordering feldspar grains. The kaolinite appears to have formed from feldspars which enclosed the pyrite. More precisely, the pyrite formed before the kaolinite formed by diagenesis in a strongly reducing and slightly acid to alkaline environment. Persistence of the

kaolinite in the weathered near-surface environment and in all horizons of the present soils indicates stability of the kaolinite through a wide range of geochemical conditions.

5. Crystals attached to the walls of voids within the rock but only partially filling the voids. Obviously, these crystals grew from material moving in through the void and (or) from material on the surface of the grain bordering the void (quartz or a feldspar).

6. Pyrite embedded within amorphous products of near-surface weathering. Usually the amorphous material is brown, yellow or black and may prevent positive identification of the pyrite. However, opacity to intense light and variable degrees of reflectance of indirect light suggest likely presence of some pyrite crystals. Sections across the strongly stained material sometimes reveal embedded pyrite crystals.

The pyrite occurrences identified in acid sandstones all appear to be secondary to sedimentation.

The size of crystals and clusters observed is highly variable. Some reflecting surfaces that are too small for positive identification may be pyrite grains smaller than 2 microns in diameter. These small faces appear black. The total mass of such material may be small but its reactivity may be high. Crystals approximating 5 microns diameter are readily identified. The diameter of some individual crystals or clusters is as great as 100 microns or even larger, but 5 to 50 microns is a common range.

Morphological forms such as those suggested by Neavel (1966) for pyrite in coal may have applications in our work, especially when variable shales as well as sandstones are included. In Neavel's terminology, most of the pyrite in our sandstones is euhedral, either isolated or aggregated. The dendritic (colloform or plumose), cleat (straight or ramifying), and blebs (cell imprinted or no cell imprints) forms may apply to some pyrite observed in the finer textured sediments and in coaly horizons or partings.

The statement in recent literature that pyrite forms prominent in sandstones like the Mahoning (Upper Freeport coal overburden) are not reactive, hence, non-acid forming, is interesting but obviously was not intended to be interpreted in an absolute sense. Our thin-section observations suggest that accessibility of pyrite to the near-surface weathering agents is a variable influencing rates of acid formation as well as type of pyrite and grain size. It seems likely that within the zone of weathering, the degree of encasement of the pyrite within weathering products such as iron, aluminum and manganese hydroxides should have a marked influence on the rate of pyrite oxidation regardless of the chemical or biological steps involved. Appearances suggest, also, that crystals which have grown from hairline cracks within sand grains are less accessible to weathering agents than crystals on grain boundaries or lining larger voids.

Acid Producing Potential of Pyritic Materials

The acidity that may develop from the oxidation of pyrite in overburden materials has been determined in two ways. Using the stoichiometry between pyrite and potential sulphuric acid (Hanna and Grant, 1962; Singer and Stumm, 1970) it can be calculated that for material containing 0.1% sulfur, all as pyrite, complete oxidation will yield a quantity of sulfuric acid that will require 6,250 pounds of calcium carbonate to neutralize one thousand tons of material.

Analyses for total sulfur in old (5 to 30 year old) spoils indicate that considerable sulphur remains for at least this long. To be sure, it has not been demonstrated that the persistent sulfur content is entirely pyritic. In fact, with many kinds of old samples, much of the sulphur may be in organic or other forms. If so, this might influence the failure of the peroxide method to give consistent results with old spoils, as indicated in following paragraphs.

The potential acidity that a spoil material can develop has been demonstrated for some materials by direct chemical measurement. Treatment of pulverized (250 u) spoil materials with 30% H_2O_2 results in the oxidation of reduced sulfur to titratable sulfuric acid. An equivalence between titratable acidity generated upon H_2O_2 treatment and total sulfur content has been shown in a comparative study involving selected sandstone and shale samples. Statistical treatment of the data (Table 3) shows the close relation between total sulfur and titratable potential acidity in 69 shale and sandstone samples. However, with 44 samples of old spoil, representing a wide variety of materials in terms of texture, organic content, and degree of weathering, no consistent relationship was obtained.

Certain aspects of determining potential acidity by a H_2O_2 method in old spoils that demand future investigation are (1) amounts of sulfate, organic, and pyritic sulfur forms, (2) effect of organic matter in decomposing the H_2O_2 before it can act upon the pyrite, (3) effect of elements such as aluminum, calcium and iron released during weathering of the old spoils. Data obtained from analyses of fresh sandstone and shale samples show that the hydrogen peroxide oxidation procedure outline in Section VI can be effectively used to measure the amount of acid that certain rock specimens can be expected to generate upon prolonged exposure to weathering.

Summary

Total sulphur determinations, (reflecting pyritic and organic sulphides) supported by petrographic observations and acid measurement by treatment with hydrogen peroxide, have established that unweathered Lower Mahoning sandstone and underlying shales, although of non-marine origin, contain sufficient finely disseminated pyrite to account for observed mineral acidity and toxicity of mine spoils and waters in central Preston County, West Virginia. However, within the weathered zone of the sandstone, commonly recognized by brown and yellow iron oxide colors (high chromas) pyrite has been destroyed by oxidation. The remaining rock is acid and low in soluble compounds, but it retains no reserve of potential acidity nor associated toxicity. Weathering depth in this particular rock has been approximately 6 meters, and deeper along old fracture planes. Different weathering depths are expected in other lithologies.

Additional details about sulphur and weathering depth are being published elsewhere (Grube et al., in process, 1971b).

Table 3

Statistical comparison of acidity generated by sample treatment with H_2O_2 with percent total sulfur in three groups of samples.

Sample Type	No. of Samples	Range of Total Sulfur %	Meq H^+/100g (Y) vs % Total Sulfur (X)			
			r^2	Y = a + b X		C.I. $_{.95}$(Y)
				a	b	
Sandstone	35	.009 - .810	.728	-0.641	37.5875	6.9
Shale	34	.025 - 2.90	.864	-4.4018	43.6002	20.6
Sandstone + Shale	69	.009 - 2.90	.862	-2.5368	42.3889	11.0
Old Spoil	44	.001 - .780	.056	2.2442	6.4894	3.8

SECTION IX

CHEMISTRY, MINERALOGY AND WEATHERING OF PROFILES

The rock chip samples taken from locations A, C, E, H and L (see Section VII) were analyzed for pH, exchangeable bases, exchangeable aluminum, free aluminum, manganese and iron, total iron, total calcium, potassium, copper, manganese and zinc. These analyses were carried out for several reasons: (1) to measure native acidity of rock material; (2) to determine the potential of this material to produce acidity; (3) to establish areas (depth) rich in pyritic or other potentially toxic material; (4) to evaluate nutrient contents which could become available to plants due to weathering of these rocks; and (5) to compare properties of rock material with that of the soils which are presently found above these unweathered rocks at the above mentioned locations.

Samples were ground to pass a 60 mesh sieve. Rock chip and soil pH measurements were made with a glass electrode pH meter, using 2:1 rock chip:water ratio and 1:1 soil:water ratio with a 30-minute equilibration period. Ammonium acetate (pH 7) extractable Ca, Mg, and K; and KCl extractable Al were determined using a Perkin-Elmer 403 Atomic Absorption instrument.

Rock chip samples, taken in 32 cm (12.5 inch) increments, were analyzed for distribution of exchangeable bases, Al and pH, at several locations (Tables 4, 5, 6, 7, 8). Rock chip samples started below the soil with sample increment No. 1 (3 to 5 feet (90 to 150 cm) below original land surface), and continued to near the coal seam.

pH

At Site A (Table 4) and Site L (Table 5) the pH of rock chip samples ranged from 5.3 to 5.8 within the weathered zone (samples 1 to 20), and in the unweathered zone, from 6.3 to 8.0 for the A series (samples 21 to 38) and 6.6 to 7.3 for the L series (21 to 48). No significant difference in pH with depth was observed at the other three locations (C, E and H) (Tables 6, 7, 8). At these locations pH was in the acid range. High pH at A and L (unweathered zone) may have resulted from alkaline earth cations or carbonates deposited during sedimentation.

Exchangeable Bases

The top 20 feet (6 meters) of rock material at all five locations were low in exchangeable bases (Ca, Mg and K) and low in pH. Below this depth, exchangeable bases at locations A, L and H increased several

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Table 4

Exchangeable bases (meq/100g) in rock chip samples from location A.

Depth Increments	pH	Ca	K	Mg	Al
2	5.3	0.20	.15	.05	0.60
3	5.5	0.10	.11	.05	0.75
4	5.3	0.10	.07	.05	0.28
5	5.3	0.40	.15	.10	0.47
6	5.4	0.50	.20	.15	0.61
7	5.5	0.80	.20	.20	0.23
8	5.6	1.00	.16	.30	0.50
9	5.7	1.00	.16	.30	0.30
10	5.7	1.20	.18	.40	0.19
11	5.9	1.00	.17	.34	0.33
12	5.7	0.80	.17	.30	0.29
13	5.7	0.80	.17	.30	2.28
14	5.6	0.70	.22	.28	0.42
15	5.6	0.50	.16	.10	0.95
16	5.8	0.30	.12	.10	0.71
17	5.1	0.20	.12	.10	0.57
18	5.2	0.70	.15	.20	0.00

Table 4 (continued)

Depth Increments	pH	Ca	K	Mg	Al
19	6.0	1.50	.17	.40	0.00
20	5.2	1.10	.18	.38	0.00
21	6.3	1.50	.14	.42	0.00
22	7.7	3.40	.15	1.10	0.00
23	7.7	2.80	.17	.90	0.00
24	7.5	2.80	.17	.90	0.00
25	8.0	3.90	.16	1.25	0.00
26	7.8	2.80	.15	1.00	0.00
27	7.8	2.80	.16	1.00	0.00
28	8.0	3.30	.18	1.20	0.00
29	7.2	3.30	.17	1.25	0.00
30	7.0	3.30	.17	1.25	0.00
31	7.5	2.60	.16	1.00	0.00
32	7.5	3.10	.20	1.20	0.00
33	7.3	2.80	.16	1.20	0.00
34	7.6	3.10	.20	1.20	0.00
35	6.9	2.00	.17	1.00	0.00
36	7.0	2.00	.17	.70	0.00
37	7.1	1.80	.18	.70	0.00
38	6.3	1.30	.22	.42	0.00

Table 5

Exchangeable bases (meq/100g) in rock chip samples from location L.

Depth Increments	pH	Ca	K	Mg	Al
1	5.3	0.85	0.23	0.18	4.85
2	5.1	0.45	0.17	0.12	1.65
3	5.1	0.25	0.19	0.16	2.70
4	5.4	0.375	0.18	0.17	1.45
5	5.4	0.55	0.13	0.22	1.30
6	5.4	0.40	0.11	0.12	0.60
7	5.5	0.20	0.13	0.07	0.08
8	5.6	0.22	0.17	0.12	0.20
9	5.7	0.20	0.24	0.14	0.32
10	5.7	0.19	0.17	0.1	0.20
11	5.6	0.35	0.27	0.22	0.80
12	5.3	0.70	0.22	0.45	0.90
13	5.4	1.0	0.26	0.64	0.20
14	5.4	0.95	0.23	0.52	0.32
15	5.5	0.55	0.23	0.48	0.00
16	5.6	0.65	0.21	0.32	0.00
17	5.9	0.52	0.15	0.20	0.00
18	5.5	----	----	----	0.00

Table 5 (continued)

Depth Increments	pH	Ca	K	Mg	Al
19	6.1	1.1	0.23	0.42	0.00
20	6.5	4.2	0.24	1.34	0.00
21	6.6	4.2	0.16	1.25	0.00
22	7.2	5.5	0.12	2.58	0.00
23	7.2	5.2	0.21	2.52	0.00
24	7.2	4.12	0.14	1.17	0.00
25	7.1	4.6	0.17	1.47	0.00
26	6.6	1.15	0.19	0.33	0.00
27	7.1	3.65	0.18	1.17	0.00
28	6.8	1.62	0.25	0.48	0.00
29	6.7	1.62	0.25	0.48	0.00
30	7.1	3.15	0.23	1.1	0.00
31	7.1	2.72	0.24	0.85	0.00
32	7.3	5.21	0.19	2.2	0.00
33	6.7	2.95	0.23	1.52	0.00
34	7.1	4.4	0.22	1.85	0.00
35	7.3	3.45	0.19	1.32	0.00
36	7.1	3.02	0.23	0.9	0.00
37	6.7	2.62	0.21	0.8	0.00

Table 5 (continued)

Depth Increments	pH	Ca	K	Mg	Al
38	6.8	1.4	0.21	0.42	0.00
39	6.6	2.48	0.22	0.9	0.00
40	7.0	4.42	0.17	1.65	0.00

Table 6

Exchangeable bases (meq/100g) in rock chip samples from location C.

Depth Increments	pH	Ca	K	Mg	Al
13	---	0.60	0.22	0.32	0.47
14	5.1	0.80	0.18	0.44	0.47
15	5.1	-.60	0.14	0.36	0.23
16	5.5	0.80	0.20	0.56	0.00
17	5.4	0.80	0.20	0.49	0.00
18	5.5	0.90	0.16	0.49	0.00
19	5.5	1.00	0.18	0.52	0.00
20	5.7	1.10	0.24	0.52	0.00
21	5.7	0.80	0.18	0.36	0.00
22	5.7	0.80	0.20	0.40	0.00
23	5.7	0.00	0.18	0.32	0.00
24	5.4	1.00	0.22	0.56	0.00
25	5.5	0.80	0.22	0.48	0.00
26	5.7	----	----	----	0.00
27	5.6	0.80	0.20	0.36	0.00
28	5.3	0.80	0.22	0.36	0.00
29	5.2	0.60	0.17	0.28	0.00

Table 6 (continued)

Depth Increments	pH	Ca	K	Mg	Al
30	5.4	0.60	0.18	0.44	0.00
31	---	----	----	----	0.00
32	---	----	----	----	0.00
33	5.2	0.90	0.24	0.29	0.00
34	---	----	----	----	0.00
35	5.0	0.70	0.24	0.28	0.00
36	5.2	0.70	0.17	0.24	0.00
37	5.0	0.60	0.20	0.48	0.00
38	5.0	1.10	0.22	0.40	0.00
39	5.1	1.00	0.21	0.28	0.00
40	5.3	0.80	0.21	0.36	0.00
41	5.1	0.60	0.20	0.28	0.00
42	5.0	0.60	0.17	0.28	0.00
43	5.3	0.70	0.24	0.29	0.00
44	5.1	0.80	0.14	0.30	0.00
45	4.7	0.70	0.20	0.30	0.00
46	---	----	----	----	0.00
47	---	----	----	----	0.00
48	4.9	1.20	0.20	0.29	0.00

Table 7

Exchangeable bases (meq/100g) in rock chip samples from location E.

Depth Increments	pH	Ca	K	Mg	Al
1	4.8	0.45	0.41	0.50	4.20
2	5.2	1.00	0.35	1.00	3.80
3	5.0	2.20	0.28	1.78	1.75
4	5.1	2.70	0.40	1.98	0.67
5	5.4	1.60	0.38	1.30	0.50
6	4.8	2.20	0.38	1.94	0.70
7	5.3	0.75	0.48	0.41	0.90
8	5.2	1.20	0.36	1.20	0.00
9	5.4	0.90	0.39	0.70	0.70
10	6.1	1.00	0.32	0.80	0.68
11	5.2	----	----	----	0.33
12	5.6	0.90	0.42	0.88	0.33
13	5.3	0.90	0.27	0.74	0.10
14	5.5	0.90	0.22	0.54	0.00
15	5.9	0.90	0.20	0.70	0.00
16	6.3	1.00	0.31	1.00	0.00
17	6.2	0.90	0.20	0.88	0.00

Table 7 (continued)

Depth Increments	pH	Ca	K	Mg	Al
18	6.4	1.20	0.20	1.12	0.00
19	6.0	1.00	0.22	1.00	0.00
20	6.4	0.90	0.20	0.60	0.00
21	6.3	1.00	0.15	0.74	0.00
22	6.5	1.45	0.24	1.30	0.00
23	6.0	1.60	0.24	1.38	0.00
24	6.5	0.90	0.28	1.52	0.00
25	6.3	1.45	0.30	0.64	0.00
26	---	0.60	0.33	0.64	0.00
27	5.6	0.60	0.27	0.60	0.00
28	5.2	0.75	0.16	0.74	0.00
29	5.4	1.95	0.28	1.64	0.00
30	6.1	1.80	0.32	1.58	0.00
31	5.0	1.45	0.40	1.78	0.00
32	4.4	1.30	0.05	0.24	0.00
33	4.6	1.60	0.04	0.16	0.00
34	4.7	1.45	0.24	1.06	0.00
35	4.4	2.10	0.1	0.20	0.00
36	4.9	2.70	0.61	2.16	0.00
37	5.3	2.70	0.57	2.00	0.00

Table 8

Exchangeable bases (meq/100g) in rock chip samples from location H.

Depth Increments	pH	Ca	K	Mg	Al
4	4.3	0.65	1.10	0.1	1.3
5	4.5	0.80	0.85	0.15	1.0
6	4.4	0.65	1.40	0.10	1.7
7	4.4	0.30	1.20	0.07	1.4
8	4.6	0.50	1.25	0.1	1.7
9	4.3	0.80	1.50	0.2	1.4
10	4.3	0.40	0.70	0.1	---
11	4.7	0.30	0.95	0.1	1.0
12	4.8	0.30	0.40	0.2	1.0
13	4.9	0.30	0.70	0.15	1.1
14	4.8	0.20	0.60	0.07	1.0
15	4.7	0.20	0.60	0.07	1.0
16	4.7	0.45	0.90	0.10	1.1
17	4.9	0.65	0.80	0.20	1.4
18	4.5	0.30	0.80	0.07	1.4
19	4.1	0.40	0.70	0.20	---
20	4.5	1.60	0.75	1.20	0.8

Table 8 (continued)

Depth Increments	pH	Ca	K	Mg	Al
21	6.0	2.30	0.45	1.60	0.5
22	5.0	2.00	0.75	1.50	0.1
23	5.1	2.10	0.80	1.50	0.1
24	5.3	2.10	0.50	1.60	0.1
25	4.8	1.50	0.60	1.10	0.5
26	4.6	1.70	0.60	1.25	0.8
27	4.2	1.50	0.55	1.00	0.8
28	4.0	1.00	0.70	0.65	0.8
29	3.7	1.40	1.00	0.80	2.7
30	3.0	1.10	0.65	0.65	---
31	3.5	1.40	1.00	1.10	1.6
32	3.7	1.20	0.70	1.25	1.2
33	3.9	1.20	0.80	1.40	1.2
34	4.2	1.40	0.85	1.60	1.2
35	4.0	1.60	0.50	1.80	1.2

fold. Increase in sulfur content was also observed at these locations below the 20 feet depth. Petrographic studies of this material showed the presence of pyrite. Lack of bases in the weathered zone and accumulation of bases below twenty feet indicates that the high concentration of hydrogen ions in the upper horizons removed Ca, Mg and K from the upper weathered zone (Figures 11 and 12). High concentration of hydrogen ion and absence of pyrite in the upper layer was a result of weathering.

According to Jenny (1950) and Keller and Frederickson (1952), the presence of hydrogen ions around silicate minerals intensifies the weathering process. The decomposition of silicate minerals is accomplished through exchange reactions in which H ions replace metallic ions, which weakens the structure and accelerates additional weathering. There seems to be no doubt that hydrogen ions furnished by the oxidation of pyrite initiated disruption of crystal structures of minerals of argillaceous rock and this resulted in increasing the contents of exchangeable Al (Tables 4 to 8) and free iron oxides (to be discussed later) in the upper horizons.

Chemical Analyses of Rock Chip Samples

Elemental analyses of rock chip samples were carried out to help determine the chemical and mineralogical characteristics of the rock. This type of information is of importance to the fundamental interpretations of the chemical processes of soil development and as a background to soil fertility and toxicity interpretations. Information gained from these analyses also contributes to formulation of optimum plans for revegetation and control of soil erosion and water pollution.

An important factor controlling the rate of breakdown of rocks and minerals and genesis of secondary products is the quantity and quality of water percolating through the weathering environment. Weathering reactions are accelerated by repeated flushings of rainwater which remove soluble constituents from the mineral surfaces.

Calcium and Potassium

Total Ca and K in rock chip samples collected from various locations are given in Tables 9 and 10. In general, the upper twenty feet (6 meters) of rock chip samples at all locations contained only small amounts of Ca. Generally, Ca varied between 0.05 and 0.2 percent. The upper zones at all locations were also low in sulfur, pH and exchangeable Ca. Below the weathered zone, total Ca in rock chip samples

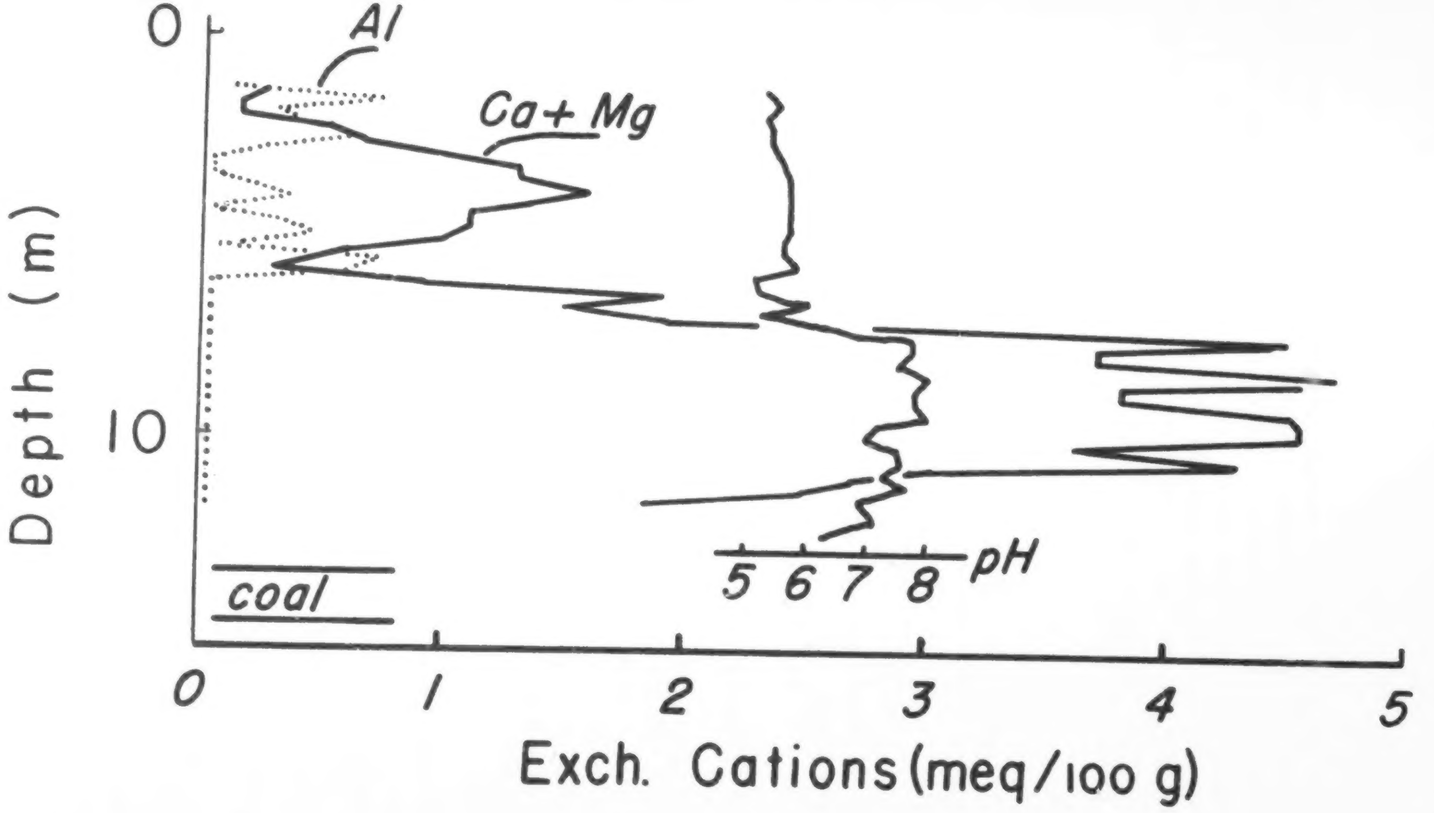

FIGURE 11. EXCHANGEABLE CATION PROFILE OF LOWER MAHONING SANDSTONE AT SITE A

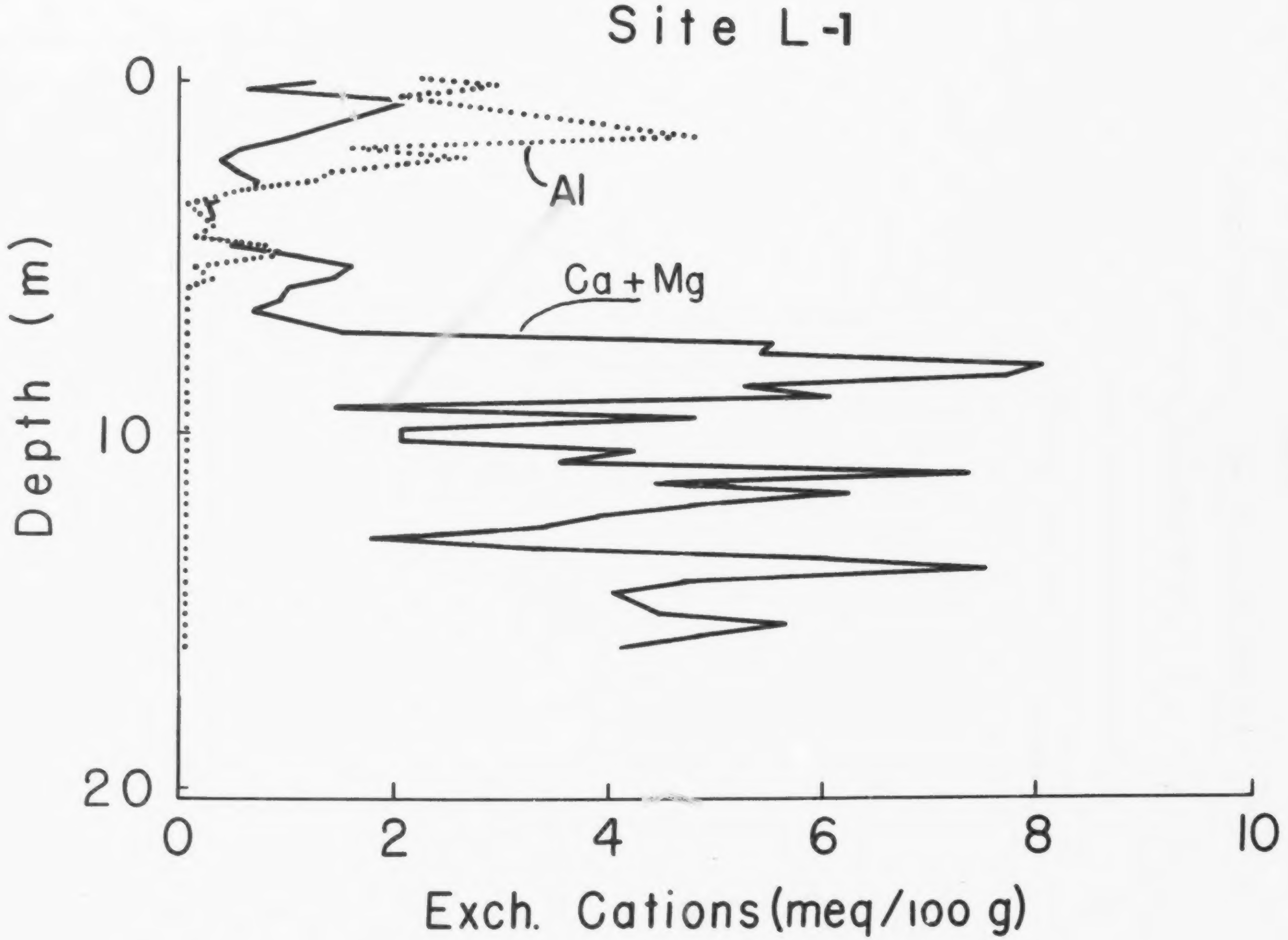

FIGURE 12. EXCHANGEABLE CATION PROFILE OF LOWER MAHONING SANDSTONE AT SITE L

Table 9

Percent total calcium in rock chip samples from selected locations.

Depth Increments	Locations				
	A	C	E	H	L
1	---	----	0.45	----	0.20
2	0.1	----	0.20	----	0.10
3	0.1	----	0.10	----	0.15
4	0.1	----	0.35	0.05	0.10
5	0.05	----	0.20	0.05	0.10
6	0.05	----	0.20	0.05	0.12
7	0.1	----	0.10	0.05	0.10
8	0.15	----	0.05	0.05	0.15
9	0.15	----	0.25	0.05	0.09
10	0.3	----	0.35	0.05	0.12
11	1.2	----	0.25	0.05	0.08
12	2.6	----	0.10	0.01	0.08
13	0.15	----	0.30	0.01	0.08
14	0.55	----	0.40	0.01	0.06
15	0.45	0.10	0.15	0.01	0.06
16	0.1	0.10	0.25	0.05	0.15
17	0.1	0.10	0.40	0.05	0.14

Table 9 (continued)

Depth Increments	Locations				
	A	C	E	H	L
18	0.05	0.10	0.35	0.05	0.06
19	0.55	0.05	0.20	0.05	0.06
20	2.3	0.05	0.30	0.01	0.20
21	0.7	0.10	0.15	0.01	0.10
22	2.05	0.10	0.10	0.25	1.02
23	1.8	0.10	0.30	0.30	1.05
24	0.3	0.10	0.20	0.30	0.20
25	1.07	0.10	0.15	0.05	0.22
26	1.55	0.10	0.30	0.05	0.03
27	0.65	0.05	0.15	0.05	0.18
28	1.25	0.05	0.14	0.05	0.03
29	0.75	0.05	0.05	0.05	0.03
30	1.55	0.05	0.10	0.05	0.20
31	3.05	----	0.45	0.05	0.22
32	1.55	----	0.40	0.05	1.00
33	0.75	0.05	0.05	----	0.25
34	1.40	----	0.15	----	0.80
35	0.75	0.05	0.05	----	0.38
36	0.65	0.10	0.15	----	3.60

Table 9 (continued)

Depth Increments	Locations				
	A	C	E	H	L
37	0.65	0.10	----	----	4.50
38	0.65	0.05	----	----	0.88
39	----	0.05	----	----	0.40
40	----	0.01	----	----	1.45
41	----	0.05	----	----	0.60
42	----	0.10	----	----	0.25
43	----	0.10	----	----	1.40
44	----	0.10	----	----	0.40
45	----	0.10	----	----	0.15
46	----	----	----	----	0.20
47	----	----	----	----	0.22
48	----	0.10	----	----	0.70

Table 10

Percent potassium in rock chip samples from selected locations.

Depth Sequence	Locations C	 E	 H	 L
1	---	2.4	----	0.70
2	---	2.4	----	0.50
3	---	3.2	----	0.65
4	---	4.2	1.10	0.50
5	---	1.7	0.85	0.50
6	---	4.2	1.40	0.22
7	---	1.0	1.20	0.15
8	---	2.5	1.25	0.30
9	---	1.8	0.50	0.40
10	---	1.5	0.70	0.30
11	---	1.6	0.95	0.60
12	---	1.6	0.40	0.85
13	1.8	1.4	0.70	0.75
14	2.1	1.5	0.60	0.72
15	1.4	1.5	0.60	0.50
16	1.8	2.1	0.90	0.40
17	1.55	1.8	0.80	0.22

Table 10 (continued)

Depth Sequence	Locations			
	C	E	H	L
18	1.15	2.4	0.80	0.40
19	1.65	---	0.70	0.45
20	1.40	1.3	0.75	0.50
21	1.15	0.7	0.45	0.22
22	1.35	1.2	0.75	0.37
23	1.65	2.0	0.80	0.90
24	1.40	1.1	0.50	0.40
25	1.55	0.9	0.60	0.22
26	1.70	0.7	0.60	0.30
27	1.35	0.6	0.55	0.30
28	1.55	0.7	0.70	0.27
29	----	3.1	1.00	0.55
30	2.10	2.3	0.65	0.50
31	----	0.9	1.00	0.50
32	----	2.4	0.70	0.52
33	2.10	2.4	0.80	0.50
34	----	0.3	0.85	0.62
35	1.70	0.7	0.50	0.30
36	1.95	2.1	----	0.50

Table 10 (continued)

Depth Sequence	Locations C	E	H	L
37	1.55	----	----	0.50
38	1.95	----	----	0.45
39	1.70	----	----	0.52
40	1.40	----	----	0.22
41	1.20	----	----	0.25
42	0.90	----	----	0.22
43	1.10	----	----	1.17
44	0.80	----	----	1.17
45	0.80	----	----	1.17
46	----	----	----	1.42
47	----	----	----	1.15
48	0.40	----	----	0.75

at locations A and L increased several fold. This was also reflected by high pH values and prominence of Ca among the exchangeable cations in lower zones at these locations, as well as the presence of free carbonates. Leaching of basic ions had not occurred in these regions. Accumulation of free carbonates probably occurred during the deposition of sedimentary material.

At the other three locations (C, E and H), Ca concentration of the lower zones did not vary significantly from the upper zones. The absence of free carbonates at these three locations indicates a difference in the conditions during deposition of the sedimentary material. From these low total Ca results one could easily visualize that exposing lower rock strata which are rich in pyrite at locations C, E and H will increase the difficulty of revegetation. These results also help in explaining the varying degrees of difficulty in establishing plant cover on apparently similar spoil materials.

Data in Table 10 show the distribution of total K relative to changes in rock depth. It is generally high at locations E and C; however, distribution of K shows no specific trend relative to changes in rock depth. Mica was distributed unevenly throughout the rock as indicated by X-ray diffraction patterns and by petrographic studies. Since no other K bearing minerals, e.g., feldspars, were observed in rock chip samples, it appears that K contents are contributed largely by the mica components of the rock material. The slight difference in the exchangeable K in weathered and unweathered zones can be explained on the basis that acid leaching of this rock material intensified weathering of mica in the weathered horizons, and this may have replenished exchangeable K in this zone. Mine spoil material derived from both weathered and unweathered zones, Sites E and C, may be capable of supplying adequate amounts of K to plants so that additional K at the time of revegetation may not be needed.

Total and Free Fe, Total Mn and Cu, and Free Mn and Al

Colored compounds, especially iron oxides, are clearly visible and often are interpreted in the field, especially in distinguishing between highly weathered and nonweathered rocks and in determining soil drainage or wetness. Like Al and Mn, iron oxides are affected by the processes of weathering and have an importance in studies of soil genesis (McKeague and Day, 1966). Iron and Mn are not only plant nutrients, but they also play a part in controlling the availability of phosphorus to plants under acid conditions. Determinations of Fe, Mn and Al in the rock strata and soil profile help, therefore, in describing the type, the distribution, the direction and the extent

Table 11

Total iron oxide (Fe_2O_3) in rock chip samples from selected locations.

Depth Sequence	Locations				
	A	C	E	H	L
1	----	----	3.50	---	7.74
2	0.58	----	3.25	---	4.00
3	1.44	----	4.40	---	6.66
4	1.61	----	5.80	3.6	6.73
5	4.03	----	4.60	3.8	8.31
6	2.73	----	3.30	2.5	4.00
7	1.87	----	3.60	1.4	2.00
8	1.82	----	2.55	0.9	4.87
9	3.17	----	5.35	6.6	1.79
10	1.87	----	6.12	0.5	1.00
11	2.01	----	5.60	0.7	2.00
12	2.89	----	1.90	2.5	1.57
13	1.44	2.9	1.35	0.8	1.29
14	2.30	2.9	2.50	1.1	2.00
15	2.30	2.6	3.50	1.5	3.01
16	2.30	3.1	1.90	1.9	3.58
17	1.16	2.0	2.25	1.6	2.50

Table 11 (continued)

Depth Sequence	Locations				
	A	C	E	H	L
18	3.17	2.0	2.10	1.5	1.79
19	1.73	2.1	1.25	1.3	4.44
20	2.16	2.1	1.00	2.9	2.93
21	5.76	4.0	2.80	0.7	1.14
22	3.03	3.4	2.60	2.7	2.86
23	4.95	1.1	4.90	5.4	1.79
24	2.74	1.2	2.50	1.8	0.28
25	2.74	1.3	1.35	1.5	0.64
26	1.15	0.9	1.90	0.4	0.57
27	2.84	1.4	1.80	0.8	0.50
28	3.31	3.7	3.50	1.1	0.78
29	4.03	3.1	2.55	2.8	0.71
30	----	---	2.05	1.6	0.71
31	2.74	---	6.05	2.5	0.78
32	----	1.4	4.80	1.3	1.57
33	2.30	---	0.30	1.9	4.87
34	1.73	1.4	0.30	1.9	2.72
35	3.60	1.4	0.15	0.8	0.64
36	1.87	1.4	0.03	---	0.86

Table 11 (continued)

Depth Sequence	Locations				
	A	C	E	H	L
37	2.59	2.6	0.35	----	0.83
38	2.88	4.0	----	----	0.71
39	----	4.0	----	----	4.58
40	----	3.7	----	----	13.47
41	----	2.0	----	----	4.58
42	----	3.4	----	----	5.59
43	----	2.0	----	----	6.16
44	----	1.4	----	----	5.01
45	----	1.4	----	----	4.58
46	----	---	----	----	4.73
47	----	---	----	----	4.00
48	----	1.6	----	----	3.44

Table 12

Percent free iron oxides (Fe_2O_3) in rock chip samples.

Depth Sequence	Locations A	C	E	H	L	F
1	----	----	3.4	----	2.22	3.00
2	0.32	----	1.9	----	2.29	2.28
3	0.49	----	3.6	----	0.64	2.80
4	1.44	----	4.8	0.87	1.79	2.50
5	1.59	----	4.3	1.51	2.29	2.45
6	1.75	----	2.0	1.49	1.23	1.90
7	1.09	----	3.0	0.58	0.61	1.70
8	1.82	----	2.1	0.38	1.27	2.38
9	1.80	----	4.2	0.17	0.80	2.75
10	1.47	----	3.5	1.38	0.24	2.45
11	1.36	----	1.8	0.47	0.61	2.17
12	1.66	----	1.2	1.96	0.61	2.75
13	0.85	0.75	1.3	0.47	0.64	2.50
14	1.82	1.10	2.2	1.10	1.43	2.20
15	1.75	0.76	1.1	1.34	1.14	0.85
16	1.47	0.75	0.9	1.44	1.14	0.75
17	0.88	1.13	1.4	1.51	0.50	0.50
18	1.55	1.30	0.9	1.37	0.53	0.30

Table 12 (continued)

Depth Sequence	Locations					
	A	C	E	H	L	F
19	0.63	0.79	1.0	0.42	0.54	0.15
20	1.51	1.30	0.2	0.38	0.37	0.50
21	2.64	1.13	1.0	0.35	1.23	0.40
22	0.65	1.37	1.3	1.01	0.65	0.65
23	1.60	0.61	4.8	1.51	0.84	0.85
24	0.47	0.84	2.2	0.39	0.53	0.40
25	0.51	1.22	0.2	1.20	1.14	0.25
26	0.79	0.79	0.7	0.59	0.38	0.37
27	1.06	1.33	0.3	1.03	1.00	0.20
28	0.61	0.65	1.0	0.19	1.00	0.20
29	0.79	1.12	0.6	0.86	0.14	0.10
30	0.27	1.22	0.2	0.02	0.05	0.15
31	0.24	----	0.0	0.37	1.00	0.20
32	0.19	----	0.2	0.19	0.45	0.20
33	0.51	0.84	0.0	0.23	0.65	0.15
34	0.34	----	0.0	0.44	0.24	0.15
35	0.27	0.58	0.0	0.22	1.29	0.65
36	0.32	1.24	0.00	----	1.00	0.48
37	----	1.40	0.00	----	0.86	0.20

Table 12 (continued)

Depth Sequence	Locations					
	A	C	E	H	L	F
38	----	1.48	----	----	1.00	0.70
39	----	1.53	----	----	0.50	0.50
40	----	1.50	----	----	0.97	0.25
41	----	1.37	----	----	0.40	----
42	----	0.26	----	----	0.43	----
43	----	1.30	----	----	0.45	----
44	----	1.33	----	----	0.21	----
45	----	1.48	----	----	1.14	----
46	----	----	----	----	0.21	----
47	----	----	----	----	0.22	----
48	----	1.53	----	----	0.20	----

of weathering and may be used to interpret fertility problems related to phosphate availability and toxic levels of Fe, Mn and Al.

Total and Free Iron

Free and total iron oxides are listed in Tables 11 and 12. Although distribution of free iron oxides is somewhat erratic with rock depth, the overall trend is a decrease in the unweathered rock. This is not an unusual property of rock material. With the exception of the E location, free iron oxide contents vary between 0.5 and 3.0%. This can be considered normal for this type of rock material in a weathered zone. It is interesting that at location L, only a small fraction of the total iron oxide is present in free iron oxide form, while at other locations, between 50 and 85% of the total iron oxide is present in the free iron oxide form in the weathered zone (Tables 11 and 12). The increase in the free iron oxide/total iron ratio indicates more advanced weathering in the upper zones at location A, C, E and H. This also indicates that further exposure of this zone will not produce more reactive iron and as a result, maintenance of phosphorus availability may be eased.

Considering total levels of iron oxides at F, exposure of this material may result in increasing levels of free iron oxides, which could intensify phosphate fixation if proper liming is not carried out prior to applying phosphorus fertilizers.

Since quantities of pyrite found at each location were too low to account for total amounts of iron oxides, some of the total iron must have come from another source. Mica which was common in these rocks, (petrographic observations) is believed to have contributed to the remaining amount of total iron oxides.

Total and Free Mn

Free and total Mn concentrations in the rock were generally low (Tables 13 and 14), with the only major variability found in the upper weathered zone at L. It is interesting to note that in most cases, between 80 and 95% of the total Mn is present in free Mn form. This means that most of the total Mn is present in easily reducible form. At H (Table 13), total Mn concentrations are as low as 10 ppm. Addition of lime to this spoil may lead to insufficient amounts of available Mn for some plants. On the other hand, manganese toxicity to plants may occur at L under very acid conditions.

Table 13

Total manganese (ppm) in rock chip samples from selected locations.

Depth Increments	Locations			
	L	C	E	H
1	550	---	100	---
2	425	---	250	---
3	620	---	300	---
4	900	---	1000	60
5	300	---	500	440
6	150	---	500	320
7	100	---	100	40
8	150	---	200	20
9	150	---	400	40
10	100	---	630	20
11	100	---	550	10
12	100	---	450	10
13	50	200	250	10
14	50	120	150	20
15	250	200	250	20
16	500	80	250	40
17	620	160	300	10

Table 13 (continued)

Depth Increments	Locations			
	L	C	E	H
18	200	160	150	10
19	1050	200	250	20
20	820	120	150	160
21	200	200	1000	340
22	550	280	450	210
23	620	360	150	300
24	100	120	350	100
25	150	120	350	40
26	50	240	450	40
27	100	80	650	20
28	100	200	1000	20
29	100	80	350	40
30	100	400	350	10
31	100	---	450	40
32	300	---	250	40
33	670	80	----	60
34	450	---	----	40
35	100	80	000	40
36	125	200	000	---

Table 13 (continued)

Depth Increments	Locations			
	L	C	E	H
37	100	560	000	---
38	100	360	---	---
39	670	320	---	---
40	2250	280	---	---
41	670	360	---	---
42	350	400	---	---
43	500	200	---	---
44	300	160	---	---
45	250	80	---	---
46	400	---	---	---
47	300	---	---	---
48	200	80	---	---

Table 14

Free Mn and free Al (ppm) in rock chip samples from selected locations.

Depth Increments	A		C		E		H	
	Al	Mn	Al	Mn	Al	Mn	Al	Mn
1	---	---	---	---	---	---	---	---
2	550	50	---	---	---	---	---	---
3	660	20	---	---	---	---	---	---
4	770	50	---	---	---	---	1100	40
5	1100	50	---	---	---	---	1980	220
6	1100	100	---	---	---	---	1650	310
7	770	40	---	---	---	---	820	40
8	1100	250	---	---	---	---	550	10
9	880	300	---	---	---	---	2860	10
10	660	100	---	---	---	---	780	10
11	660	50	---	---	---	---	790	10
12	770	250	---	---	---	---	770	10
13	550	40	550	100	---	---	770	10
14	850	320	660	55	---	---	770	10
15	880	190	660	125	---	---	880	40
16	770	80	550	25	---	---	990	75
17	660	100	770	140	---	---	1430	100

Table 14 (continued)

Depth Increments	A		C		E		H	
	Al	Mn	Al	Mn	Al	Mn	Al	Mn
18	440	310	770	125	---	---	880	10
19	440	725	550	180	---	---	880	10
20	550	250	880	100	---	---	660	40
21	550	125	550	170	---	---	440	50
22	330	80	660	100	---	---	660	75
23	440	190	440	50	---	---	770	300
24	660	50	550	100	---	---	550	50
25	330	50	550	100	---	---	880	20
26	330	50	550	50	---	---	660	40
27	440	50	770	220	---	---	220	10
28	440	50	550	50	---	---	220	10
29	550	100	880	175	---	---	1210	20
30	----	---	1320	200	---	---	550	10
31	440	50	----	---	---	---	550	10
32	----	---	----	---	---	---	550	10
33	440	50	880	40	---	---	440	10
34	440	50	----	---	---	---	440	10
35	550	100	660	55	---	---	440	10
36	660	100	880	175	---	---	---	---

Table 14 (continued)

Depth Increments	A		C		E		H	
	Al	Mn	Al	Mn	Al	Mn	Al	Mn
37	660	50	880	500	---	---	---	---
38	880	50	770	320	---	---	---	---
39	---	---	880	240	---	---	---	---
40	---	---	990	250	---	---	---	---
41	---	---	880	180	---	---	---	---
42	---	---	770	335	---	---	---	---
43	---	---	550	170	---	---	---	---
44	---	---	990	100	---	---	---	---
45	---	---	1540	25	---	---	---	---
46	---	---	----	---	---	---	---	---
47	---	---	----	---	---	---	---	---
48	---	---	1540	10	---	---	---	---

Free Al

Distribution of free Al in rock at various depths and locations is shown in Table 14. The high concentration of free Al, in addition to free Mn and Fe oxides in the upper 20 feet of rock strata, indicates intensive weathering. There is a relatively wide range in the amounts of free Al between locations studied; however, free Al contents are generally low below 20 feet at several locations and are clearly related to the exchangeable Al (Tables 4 to 8). Evidently free Al in the weathered zones of this rock material resulted from reactions of clay minerals with the acids produced by the oxidation of the sulfides. Free Al present at this stage may not pose difficult problems in the establishment of cover crops provided proper treatment with lime is carried out in advance of revegetation.

Total Cu

Data in Table 15 show distribution of Cu in rock material at several locations. Concentration of Cu varied with location, between 4 and 26 ppm at location H and over 100 ppm at location C. In normal soils, over 50 ppm Cu is considered very high and below 10 ppm is considered low. At other locations, Cu was between 20 and 50 ppm. According to Mitchell (1964) the total content of trace elements can be a good indication of their potential availability to plants. Study of several West Virginia soils show Cu content between 10 and 20 ppm, which is acceptable for normal plant growth. Soils which will develop from weathering of rock at location C will certainly contain higher amounts of Cu. The implications of this on Cu availability to plants will emerge later, but it is relevant at this point to mention that application of waste materials such as sewage sludges, in which Cu content may be around 1000 ppm may make revegetation difficult on such mine spoils as C. Plants grown on C rock in the greenhouse showed yellowing of leaves which may be an indication of Cu toxicity. Unfortunately, chemical analyses of plants were not carried out. Future studies should include chemical analyses of plants grown on mine spoil material.

Chemical Characteristics of Several Soil Profiles

Exchangeable Bases and Al

Soils at all locations, except E and C, were very low in exchangeable bases (Ca, Mg and K). Oxidation of the pyrite has resulted in leaching of parent rock with sulfuric acid before exposure to soil forming processes. As a result, these soils (except E and C, which were recently limed) are high in exchangeable Al (Tables 16 and 17). It is interesting

Table 15

Total Cu (ppm) in rock chip samples

from selected locations.

Depth Increments	Locations			
	C	E	L	H
1	---	50.5	50	--
2	---	40.0	25	--
3	---	55.0	45	--
4	---	45.0	45	12
5	---	50.0	52	12
6	---	45.0	30	20
7	---	25.0	15	20
8	---	40.0	35	20
9	---	40.0	25	12
10	---	35.0	30	12
11	---	25.5	25	6
12	---	30.5	10	20
13	94	50.5	30	12
14	122	25.0	30	12
15	142	30.5	30	6
16	338	30.5	10	4
17	60	45.0	15	4

Table 15 (continued)

Depth Increments	Locations C	E	L	H
18	42	30.5	25	6
19	88	10.0	10	6
20	198	45.0	10	12
21	318	40.0	5	6
22	122	20.0	15	12
23	376	20.0	25	12
24	206	25.0	0	4
25	180	45.0	0	12
26	150	5.0	0	12
27	118	20.0	0	12
28	72	20.0	0	20
29	6	30.5	0	42
30	202	50.0	0	20
31	---	30.5	55	24
32	---	55.0	28	20
33	296	20.0	28	22
34	---	20.0	25	26
35	126	5.0	25	12
36	136	40.0	25	--

Table 15 (continued)

Depth Increments	Locations			
	C	E	L	H
37	304	20.0	20	--
38	82	----	20	--
39	154	----	25	--
40	76	----	18	--
41	94	----	25	--
42	108	----	--	--
43	122	----	35	--
44	76	----	--	--
45	72	----	40	--
46	---	----	35	--
47	---	----	25	--
48	25	----	--	--

Table 16

Some chemical properties of Dekalb soil taken from three locations (A, C and H).

Location and Horizon	Depth Inches	pH in H_2O (1:1)	Organic Matter %	Total Fe_2O_3 %	Free Fe_2O_3 %	CEC per 100 g Meq	Exchangeable Cations per 100 g				
							Ca Meq	Mg Meq	K Meq	Al Meq	Base Saturation %
A											
A_1	0-2	5.1	10.6	1.5	1.4	16.4	4.90	0.250	0.185	0.80	32.6
A_2	2-8	4.5	5.7	1.8	1.4	5.8	1.30	0.050	0.100	1.12	25.0
B	11-18	4.5	1.1	2.4	1.9	6.6	1.10	0.050	0.150	1.70	19.1
C											
Ap	0-6	4.5	5.2	2.4	2.1	10.0	7.80	0.650	0.485	0.25	25.0
A_3	6-10	4.5	3.6	2.9	2.0	6.6	1.70	0.050	0.235	1.60	30.1
B	12-18	4.5	2.0	2.9	2.3	6.2	0.95	0.050	0.150	2.00	18.5
C	18-22	4.4	0.4	2.9	1.3	6.2	0.95	0.050	0.130	1.90	18.2
H											
Apl	0-2	4.5	8.4	1.43	1.43	9.5	3.30	0.20	0.26	1.3	39.5

Table 16 (continued)

Location and Horizon	Depth Inches	pH in H_2O (1:1)	Organic Matter %	Total Fe_2O_3 %	Free Fe_2O_3 %	CEC per 100 g Meq	Exchangeable Cations per 100 g				
							Ca Meq	Mg Meq	K Meq	Al Meq	Base Saturation %
Ap2	2-7	4.5	4.1	2.09	1.29	8.0	0.92	0.05	0.11	2.0	13.5
B_21	7-13	4.3	1.3	2.32	1.29	8.0	0.20	0.02	0.09	2.8	3.9
B_22	13-21	4.3	1.5	2.17	1.40	9.5	0.21	0.03	0.12	4.0	3.8
C	21-27	4.3	0.6	2.43	1.20	11.5	0.21	0.06	0.14	2.2	3.6

Table 17

Some chemical properties of soils taken from two locations (E and L).

Location and Horizon	Depth Inches	pH in H_2O (1:1)	Organic Matter %	Total Fe_2O_3 %	Free Fe_2O_3 %	CEC per 100 g Meq	Exchangeable Cations per 100 g				
							Ca Meq	Mg Meq	K Meq	Al Meq	Base Satura-tion %
E											
Ap	0-20	5.7	4.0	4.9	2.3	14.5	11.20	0.30	0.10	0.1	0.7
B_1	20-30	5.5	3.4	6.0	2.3	15.2	10.20	0.20	0.09	0.7	4.6
B_2T	30-48	5.2	2.9	5.4	2.4	15.5	3.80	0.05	0.11	3.1	20.0
BX_1	48-54	4.7	2.8	7.2	2.5	17.5	2.30	0.15	0.11	4.5	25.7
BX_2	54-68	4.7	0.1	6.8	2.5	18.5	2.40	0.30	0.11	5.9	31.9
L											
A_1	0-18	3.9	6.9	3.7	1.9	7.1	1.10	0.14	0.28	3.6	50.7
A_3	18-30	4.0	4.2	5.2	2.1	7.0	0.40	0.08	0.15	2.9	41.4
B_2T	30-48	4.2	1.1	5.1	3.3	7.4	2.00	0.15	0.16	4.2	56.7
BX_1	48-66	4.0	0.2	7.4	2.8	5.4	1.10	0.14	0.15	3.4	63.0
BX_2	66-107	4.1	0.1	8.0	2.0	5.8	0.80	0.13	0.15	3.8	65.5

that the soils are similar to the rock, between 70 and 100 per cent of the total iron being present as free iron oxide in the upper horizons, while the lower horizons show a marked decrease in free iron oxide compared to total iron content. Soils at locations E and L, which are high in total iron oxide, show a very small fraction of the total iron as free iron oxide. Low free iron oxide content of E and L soils suggest less intensive weathering of this soil. Mechanical analyses for these two soils, as discussed later, do not support this contention. Variation in the free iron oxide/total iron could be due to variation in the source of iron in the parent rock. Biotite minerals which carry iron are more resistant to weathering than pyrite, and may have influenced the free iron oxide concentration at the above mentioned locations. Petrographic analyses of parent rock at E and L locations showed presence of mica.

Mechanical Analysis

Table 18 shows results obtained for mechanical analyses of soils at five locations. Results at E and L are based on an air dry, organic matter-free basis; at locations A, C and H on the basis of air dry weight with organic matter included.

The particle size distribution of the soils at locations A, C and H were similar, with slight variability in the sand and clay contents of the H soil, which contained more sand and less clay. In these soils total clay contents ranged from 14 to 24%, being rather uniform with depth. These soils were well drained and consisted of coarse texture which reflected the influence of parent rock.

Soils developed at locations E and L showed greater variability in sand and clay fractions. Soil at E location contained less sand and more clay than the soil at location L. Both soils showed an increase in clay in the lower horizons, indicating illuviation of clay material. However, lack of prominent clay skins indicated that textural difference in parent rock may, in some cases, have contributed to greater percentages of clay in the lower horizons (B horizon). There are some evidences, such as the decrease in sand in the B horizon of the E soil, which indicated a probable textural variation in the soil parent rock. This may explain differences in the development of different soils at locations E and L. From the results of mechanical analyses, one could visualize the influence of texture of parent rock on the development of these soils.

Table 18

Mechanical analysis of soil profiles.

Location	Horizon	Depth Inches	Total Sand %	Total Silt %	Total Clay %
A	A_1	0-2	41.8	28.0	19.6
	A_2	2-8	44.8	30.9	23.9
	B	11-18	43.2	36.0	20.3
C	Ap	0-6	36.0	38.0	21.0
	A_3	6-10	41.0	34.0	17.9
	B	12-18	36.8	30.0	24.5
	C	20-21	38.6	41.6	19.8
H	Ap1	0-2	42.8	31.2	18.50
	Ap2	2-7	42.8	34.2	18.50
	B_21	7-13	45.7	24.5	17.86
	B_22	13-21	64.0	32.8	19.90
	C	21-27	54.1	31.8	14.00
E	Ap	0-20	20.3	58.6	21.1
	B_1	20-30	24.1	49.0	26.9
	B_2T	30-48	11.9	57.1	30.9
	BX_1	48-54	6.7	58.8	34.4
	BX_2	54-68	13.3	54.2	32.5

Table 18 (continued)

Location	Horizon	Depth Inches	Total Sand %	Total Silt %	Total Clay %
L	A_1	0-18	33.6	42.1	24.3
	A_3	18-30	31.2	44.6	24.2
	B_2T	30-48	32.8	37.1	30.1
	BX_1	48-66	41.1	35.1	24.0
	BX_2	66-107	41.6	40.0	18.0

Mineralogical Characteristics

Clay minerals are of major importance in influencing the physical and chemical characteristics of soils and other earth material. They may play an important part in the mechanical stability of extreme slopes and consequently soil erosion or slippage. Since knowledge of the minerals in the clay fraction would contribute toward a fundamental understanding of the chemical and physical properties of mine spoil material and its reaction to weathering or practices, detailed mineralogical studies of rock and soils were carried out.

Mineralogical analyses were carried out on coarse clay (2 to 0.2μ), medium clay (0.2 to 0.08μ) and fine clay (0.08μ) fractions separated from rock and also from soils. Magnesium saturated samples of each size fraction were glycerol saturated and parallel-oriented on glass slides for X-ray diffraction analysis (Jackson, 1956). Diffraction patterns were obtained also on K saturated samples after the following treatments: (a) K saturation and air drying; (b) K saturation and heating at 110°C; (c) K saturation and heating at 300°C; and (d) K saturation and heating at 550°C.

Diffractograms were made with a Siemens Crystalloflex IV, X-ray diffractometer, using nickel-filtered copper radiation, and a scintillation detector.

For differential thermal analyses (DTA), the clay samples were saturated with Mg. The samples were heated from 25°C to 1000°C at a rate of 15°C per minute.

X-ray patterns of oriented, Mg saturated, glycerol solvated clays separated from rock material from two locations (L and H) are shown in Figures 13 and 14. The strong peaks at 7 and 10 Å indicate that kaolinite and mica are the dominant clay minerals in rock at both locations.

Differential thermal analysis indicated the clay fraction of the rock contained 30 to 40% kaolinite. Total K analyses of rock material showed 18 to 30% mica. Small peaks at about 14.4 Å in the upper zones reflect small amounts of vermiculite at both locations. After K saturation the 14.4 Å unit cells collapsed to 10 Å, confirming presence of vermiculite. Samples taken from lower depths (unweathered zone, rich in pyrite) showed no 14 Å peak. It is also evident from Figure 14 that mica contents increase with increase in depth. These findings indicate that vermiculite formed during or shortly after pyrite oxidation which

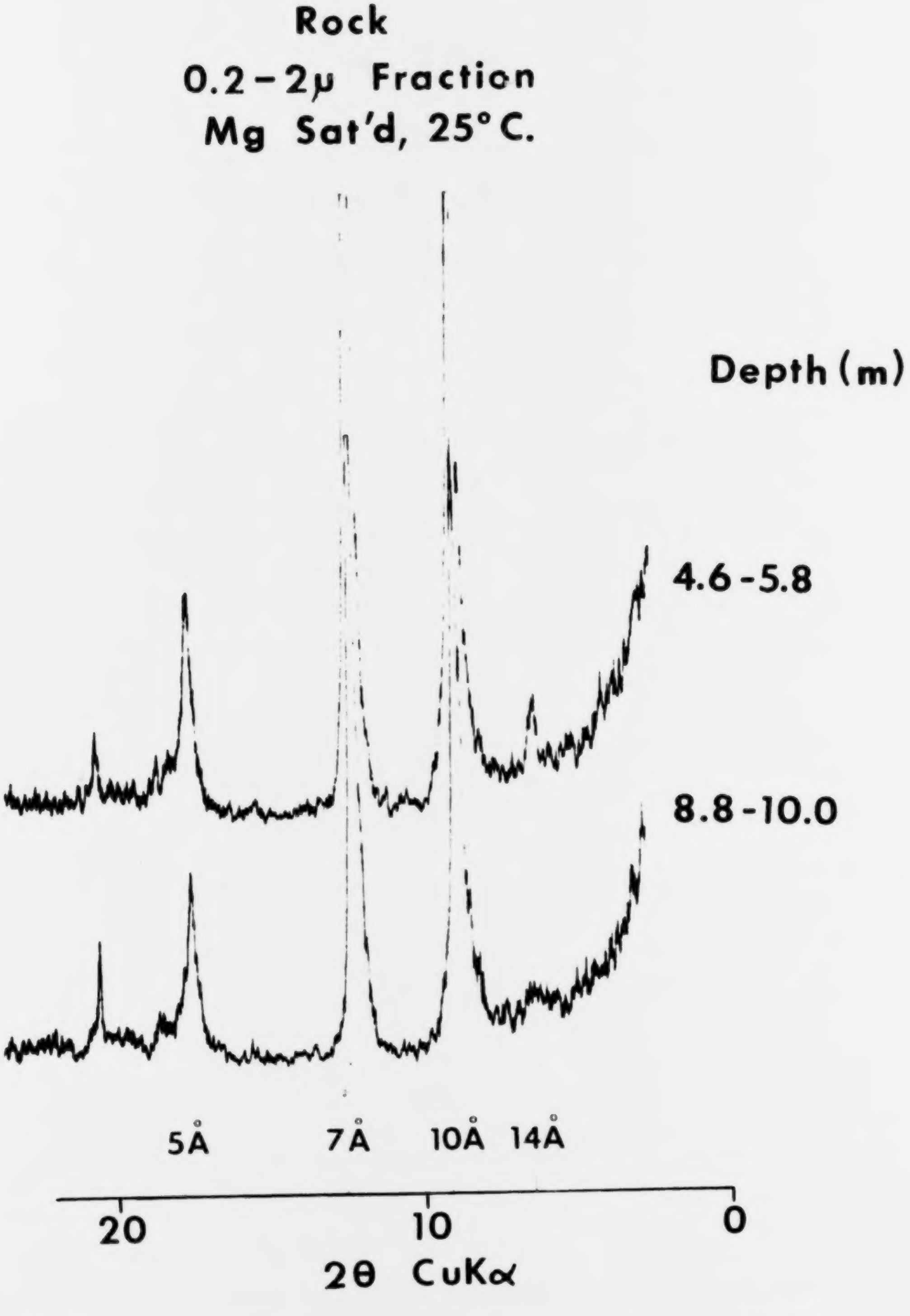

FIGURE 13. X-RAY DIFFRACTOGRAM SHOWING MINERALOGY OF WEATHERED AND UNWEATHERED LOWER MAHONING SANDSTONE

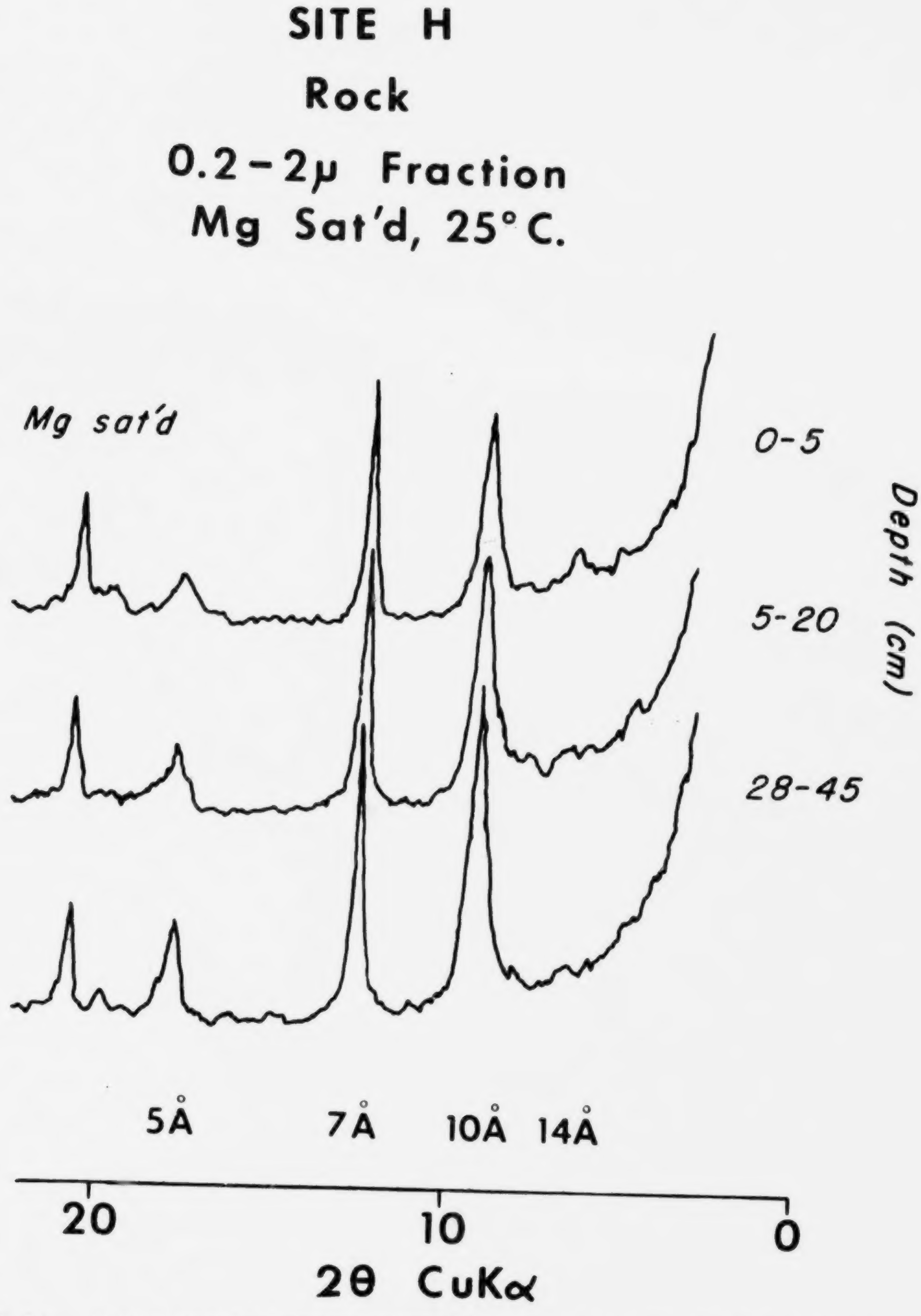

FIGURE 14. X-RAY DIFFRACTOGRAM (ROUNDED) SHOWING MINERALOGY OF ROCK AT SITE H

may have removed K from mica. Fine clay (.2u) separated from rock showed a peak at 17.7 Å indicating the presence of montmorillonite. This was observed in fine clay separated from both weathered and unweathered zones. Apparently during pyrite oxidation, some montmorillonite, which is not very stable under acid conditions, was not destroyed.

Mineralogy and Mottling of Soils

Distribution of mineral species in soil clays with depth is given in Figures 15, 16 and 17 and Table 19. X-ray diffraction analysis of the Mg-saturated samples from H location showed vermiculite as the dominant clay mineral in all horizons and at all depths (Figure 15). Kaolinite ranked second in abundance in all horizons in this soil. Mica and montmorillonite clay mineral were absent in the upper horizons as no 10 Å and 17.7 Å peaks were observed. Increase in the intensities of 10 Å and 17.7 Å peaks with depth indicated presence of mica and montmorillonite at lower depths.

Soils taken from locations E and L showed that kaolinite (7 Å peak in Figure 16 and 17) was the principal clay mineral with smaller amounts of vermiculite and mica (14 and 10 Å peaks respectively in Figures 16 and 17) in the upper horizons. In the lower horizons the amount of vermiculite decreased and mica increased. A small but prominent peak at 18 Å was also present at lower depths (Figure 17 and Table 19). This indicates presence of montmorillonite. Mineral ratings in Table 19 were developed from chemical, DTA and X-ray diffraction determinations.

Mineral contents of all soil profiles are strongly influenced by the underlying parent rock (Figures 13 and 14), which contains kaolinite, mica and small amounts of vermiculite and montmorillonite. In general, kaolinite and mica are the major clay minerals, followed by vermiculite and montmorillonite in the lower soil horizons. In the upper horizons where intensive weathering has taken place, kaolinite and vermiculite are the dominant clay minerals with minor amounts of mica and traces of montmorillonite. It is of interest that in all these profiles, there is an alteration continuum. In weathered rock and B horizons, there is expanding vermiculite which collapses on K saturation. Vermiculite in A horizons of all soils collapses only on heating to 300 or 550°C. The reason for the prominence of the vermiculite in the A horizon is not certain. Probably, as has been shown by other workers (Douglas, 1965; Hathaway, 1955; Rich and Obenshain, 1955; and Rich, 1958), the increase in the proportion of vermiculite to mica nearer the surface resulted from the removal of weathering products in

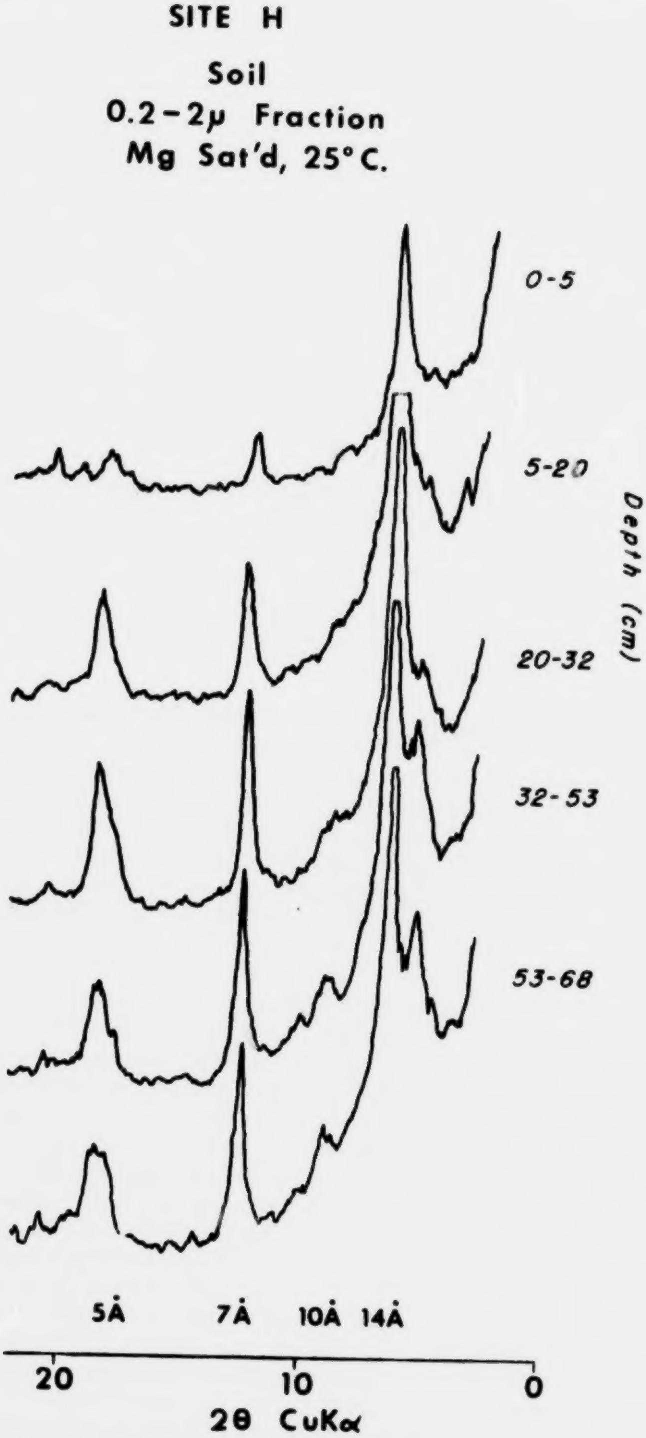

FIGURE 15. X-RAY DIFFRACTOGRAM (ROUNDED) SHOWING MINERALOGY OF SOIL AT SITE H

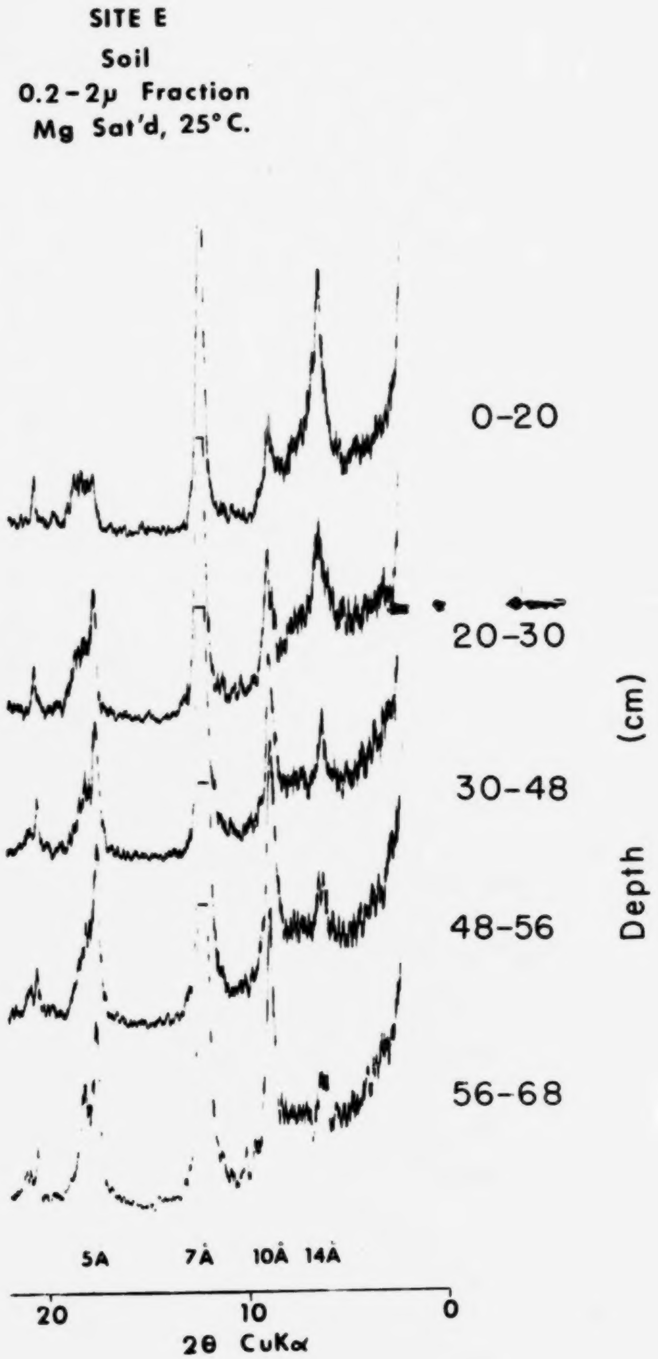

FIGURE 16. X-RAY DIFFRACTOGRAM SHOWING MINERALOGY OF SOIL AT SITE E

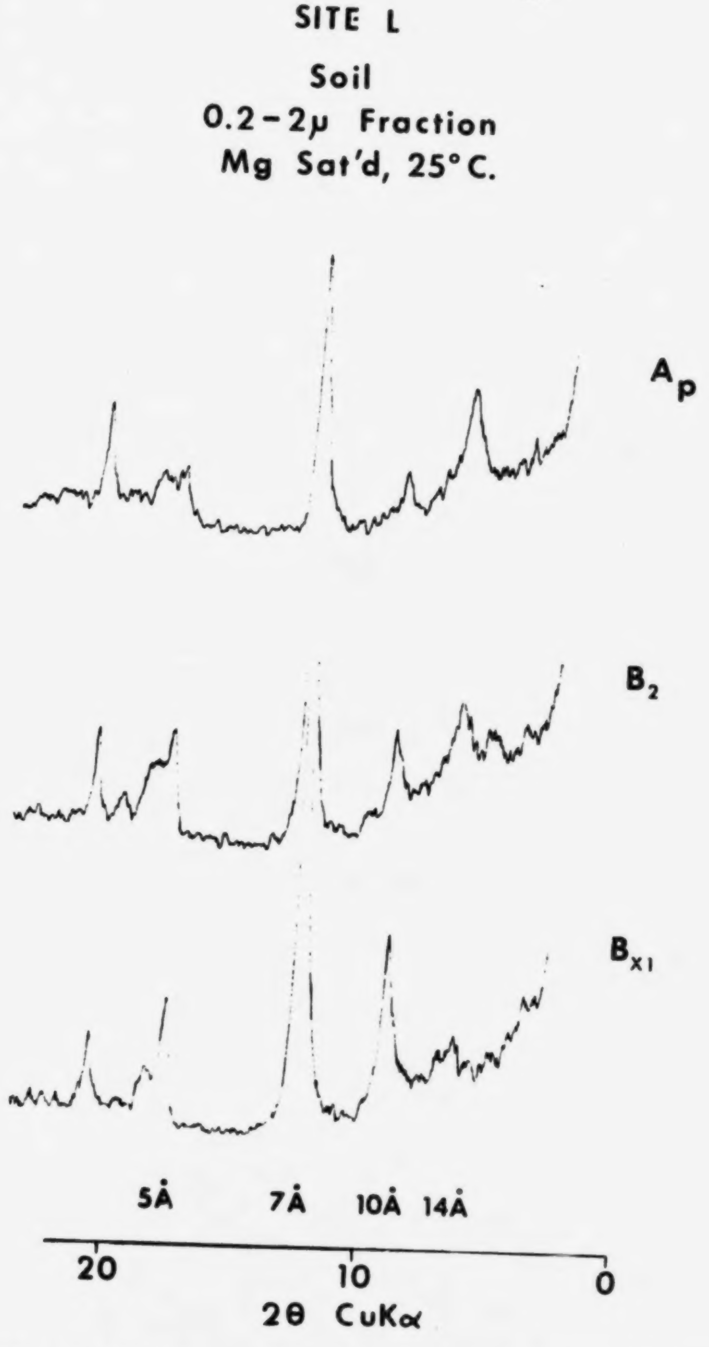

FIGURE 17. X-RAY DIFFRACTOGRAM SHOWING MINERALOGY OF SOIL AT SITE L

Table 19

Mineral composition of clay fractions of two soil profiles.

Loca-tion	Horizon	Kaol.		Mica		Vermic.		Mont.		Amorph.		Quartz	
		2-.2u	.2u	2-.2u	.2u	2-.2u	.2u	2-.2u	.2u	2-.2u	.2u	2-.2u	.2u
E	Ap	4	2	1	--	3	2	--	1	P	P	P	P
	B_1	4	2	2	1	2	1	--	1	P	A	P	P
	B_2t	4	2	3	1	2	1	1	2	P	A	P	P
	Bx_1	4	2	3	1	2	1	1	2	P	A	P	P
	Bx_2	4	2	3	2	1	1	1	2	P	A	P	P
	Hi-Chroma	4	1	3	2	1	2	1	2	A	A	P	P
	Lo-Chroma	4	2	2	1	1	1	--	--	--	P	P	P
L	A_1	3	2	1	1	2	2	--	1	P	P	P	P
	A_3	4	2	2	1	1	1	--	1	P	P	P	P
	B_2	4	2	3	1	1	1	1	1	P	A	P	P
	Bx_1	4	3	3	1	1	1	1	2	P	A	P	P
	Hi-Chroma	4	2	3	2	1	1	1	1	A	A	P	P
	Lo-Chroma	4	2	3	1	1	--	--	--	--	P	P	P

Key: Amorphous and Quartz: P = Present; A = Abundant; -- = Absent; Layer Silicates: -- = Absent; 1 = Traces; 2 = Low; 3 = Medium; 4 = High (up to 50%)

solution and continuous replenishing of vermiculite by weathering of mica. This interpretation is supported by increase in mica with increasing depth of soil profile (Figures 15, 16 and 17).

The reason for the presence of montmorillonite (least prominent clay mineral) under acid weathering conditions is not certain. It has been accepted that (2:1) layer silicate minerals such as montmorillonite are stable only in basic soils or under essentially saturated conditions, but where leaching is severe as in southeastern United States, kaolinite type minerals are expected. Considering the low pH values of these soils and weathered rocks, it is assumed that montmorillonite, occurring originally in parent rock below the water table, was encased and protected by stable crystalline or amorphous fines during pyrite oxidation and soil development.

In the course of morphological studies of soils at several locations, vertically elongated, low chroma (gray) tongues were observed in subsoils (B horizons) and in underlying sandstones at locations E and L. The physical appearance of this sandstone in the weathered zone was similar to that of the low chroma sandstone in the unweathered zone (pyrite rich) and could be mistaken for pyritic sandstone by mine operators. As a result, physical, chemical and mineralogical studies were carried out to determine the nature and source of this material. Detailed results of this investigation are given in a paper by Grube et al. (1971). Conclusions derived from this study are summarized as follows: Field observations showed that the low chroma surfaces of the sandstone may be continuous with vertically elongated low chroma zones in overlying subsoils. Chemical studies of this low chroma sandstone showed very low percentages of total sulphur (0.001%), total iron (1.10%) and free iron (0.50%). Similar total sulphur (0.001%) and more iron (total, 3.71%; free, 1.61%) were found in the high chroma interior. Mineralogical studies of low chroma and high chroma subsoil showed that low chroma material is devoid of mobile minerals (montmorillonite and amorphous), and rich in less mobile kaolinite and mica (Table 19). On the other hand, high chroma material contains more amorphous fines as well as appreciable amounts of vermiculite and montmorillonite.

From these studies, it was concluded that low chroma material in the soil and weathered rock is mainly a result of localized leaching of colored compounds (oxides and hydroxides of iron). In the field, it should be remembered that low chroma sandstone or soil occurring naturally on outside surfaces of rock or soil fragments, is not likely to contain pyrite or toxic acid. It is the low chroma (gray) unweathered sandstone interiors which are pyritic and potentially toxic.

Applicability of Mineralogical Data

Results indicate that mica has weathered to vermiculite in soil profiles and weathered rock materials studied. Moreover, vermiculite clay carries high negative charge and as a result increases cation exchange capacity. This prevents rapid leaching of exchangeable elements (either toxic or favorable) to ground water. Clay minerals like vermiculite and montmorillonite would also serve as a "buffer" by their reactions with the acid produced by the oxidation of sulfides. The reaction of acid with clay minerals may increase Al activity in solution when Ca contents are low. This requires limestone applications for establishment of cover crops.

Since clay minerals play a prominent part in determining physical and chemical properties, there is an urgent need for quantitative clay mineral information in correlated mine spoil materials. Such data should afford a means of discriminating spoils with sufficient buffering and water retention capacity to inhibit leaching of toxins and to favor maintenance of desirable pH and nutrient levels for initial and for long-time growth of cover plants.

Summary

Soil and rock profile studies from the land surface to depths as great as 62 feet (20 meters) indicate changes within the weathered zone and soil in addition to pyrite oxidation. Exchangeable Al becomes relatively high whereas exchangeable Ca, Mg and K and pH are low. Micas, which associate with kaolinite in the dominantly quartzose unweathered sandstone, change first to collapsible vermiculite and then to a non-collapsible form. Small percentages of montmorillonite, first discovered after removal of all free oxides, together with amorphous fines, tend to eluviate from surface soils and through certain spaced gray (low chroma) zones of subsoil and weathered rock. Zn concentrations occur within ranges common in productive soils. Mn has been generally low, usually in readily extractable form, but possibly in plant-toxic concentrations in some strongly acid materials. Copper concentrations have shown wide ranges, from possibly deficient to toxic for plant growth and may pose some problems in revegetation. Potassium levels, generally related to micas, are highly variable. Mg rates very low for plant growth in the weathered zone, is higher but variable in unweathered sandstone, and is relatively high in dark shales over the Upper Freeport coal. Quartz and kaolinite persist throughout the soil and rock profiles with no apparent change. Genesis of the kaolinite is uncertain. It occurs as secondary books, replacing minerals such as feldspars. Pyrite genesis in the sandstone involved replacement of quartz, mica or other minerals deposited in original sediments.

SECTION X

ROCK WEATHERING

Simulated Weathering Experiment

This part of the project involved the use of specially designed cells (modified plastic shoe boxes), similar to those described by Caruccio (1967), to contain selected rock materials during simulated weathering. Two hundred grams of one of the rock types, low chroma sandstone and high chroma sandstone or low chroma shale were placed in a cell and exposed to a continuous flow of moist air. The cells were leached twice a week for the first eight washings and once a week for the next six washings using the following scheme: To each cell 100 mls of distilled and deionized H_2O was added to 50 ml increments. The sample was allowed to soak for 10 minutes after each increment and then the cell was gently agitated to thoroughly wash the sample before the water was drained. After the sample was washed with both increments of water, the washings were centrifuged and the volume of each was recorded. Any residue from the sample left in the centrifuge tubes was returned to the proper cell. The data for the three sample types were the mean of three replicates; individual measurements were essentially the same.

Conductivity measurements were taken with a Wheatstone Bridge and a pipette cell with a constant of one. Then the washings were split with half being saved to be analyzed for Al, Fe, Ca, Mg and K. The other half was analyzed for the potentially free acidity of the rock material according to the method of Rainwater and Thatcher (1960).

The conductivity of the distilled and deionized water was checked each time the cells were leached and subtracted from the conductivity of the washings. The initial washings were highest in electrolytes for all samples and then the conductivity decreased to its lowest point on day 22. The low chroma sandstone and low chroma shale were quite close in all readings and on day 55 until the end of the experiment both samples showed a steady increase in electrolyte content of their washings. The high chroma sandstone sample was very low in all readings with its high point being on day 44.

The potentially free acidity that was produced by the low chroma sandstone and low chroma shale was low when compared to amounts produced from the same samples by the peroxide method (See Section VI). The amounts of acidity produced by the high chroma sandstone was comparable for both methods. The low chroma sandstone had the largest and quickest release of acids even though the low chroma shale has the largest

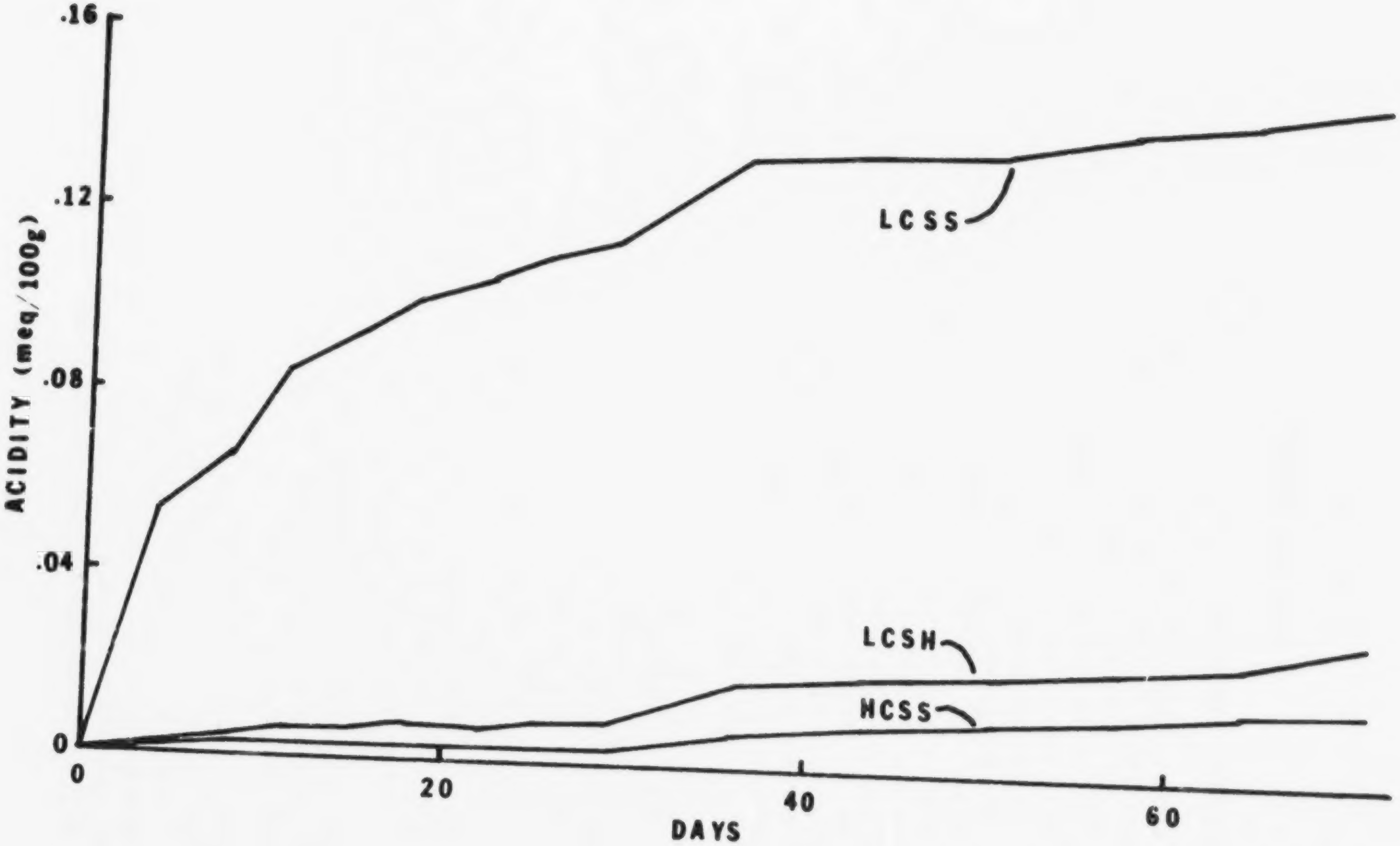

FIGURE 18. ACCUMULATIVE ACIDITY GENERATED BY SIMULATED WEATHERING OF THREE ROCK TYPES

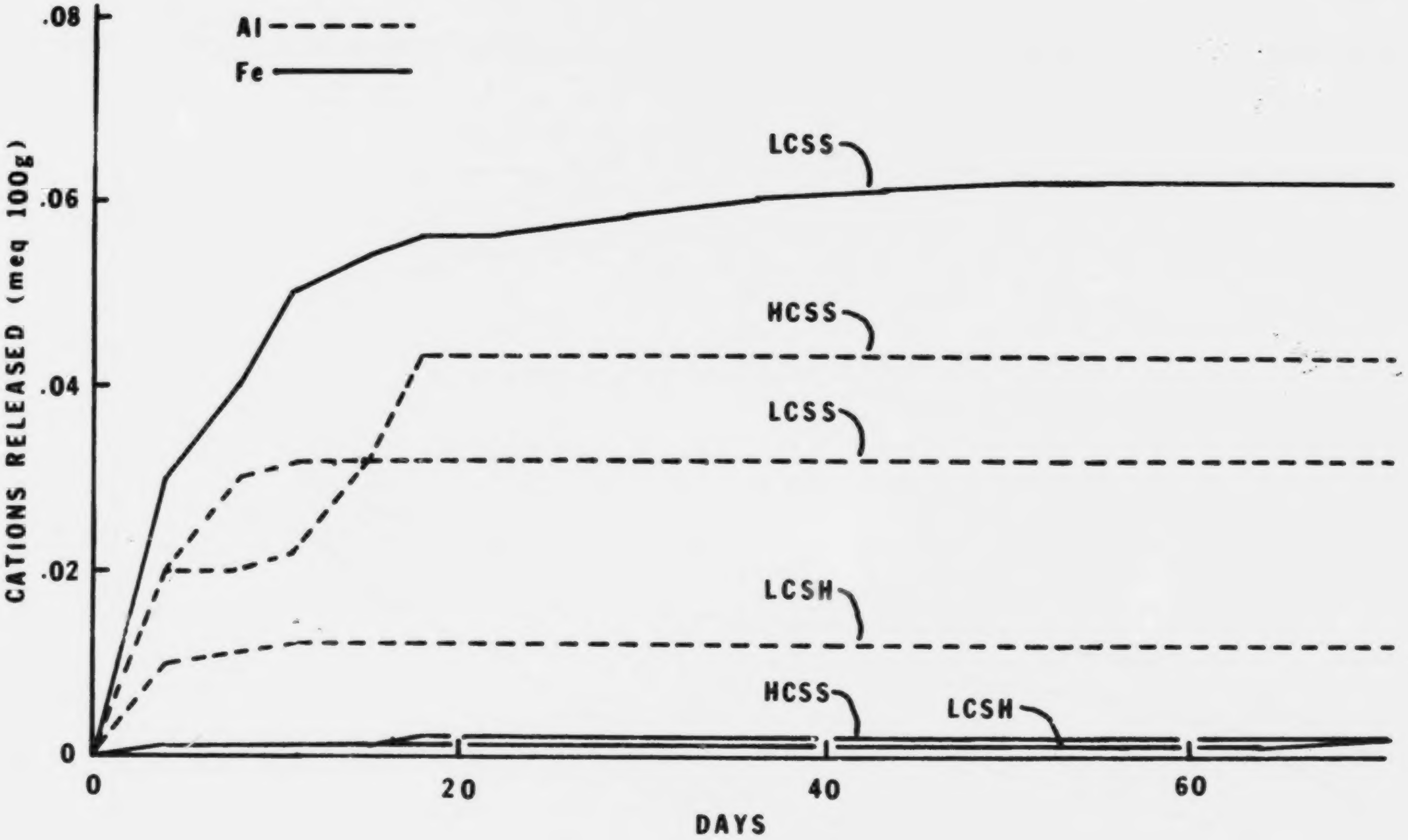

FIGURE 19. ACCUMULATIVE RELEASE OF IRON AND ALUMINUM DURING SIMULATED WEATHERING OF THREE ROCK TYPES

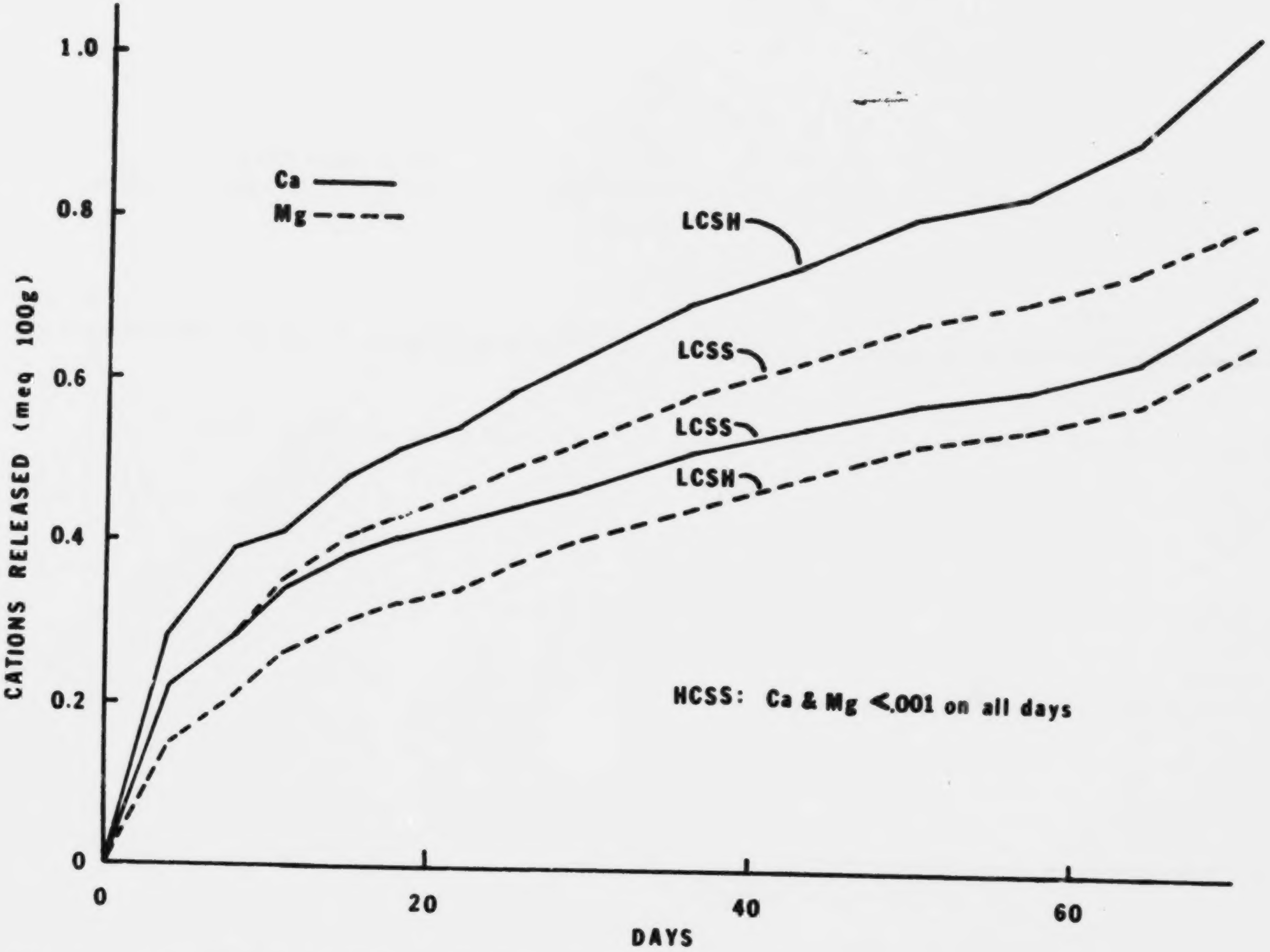

FIGURE 20. ACCUMULATIVE RELEASE OF CALCIUM AND MAGNESIUM DURING SIMULATED WEATHERING OF THREE ROCK TYPES

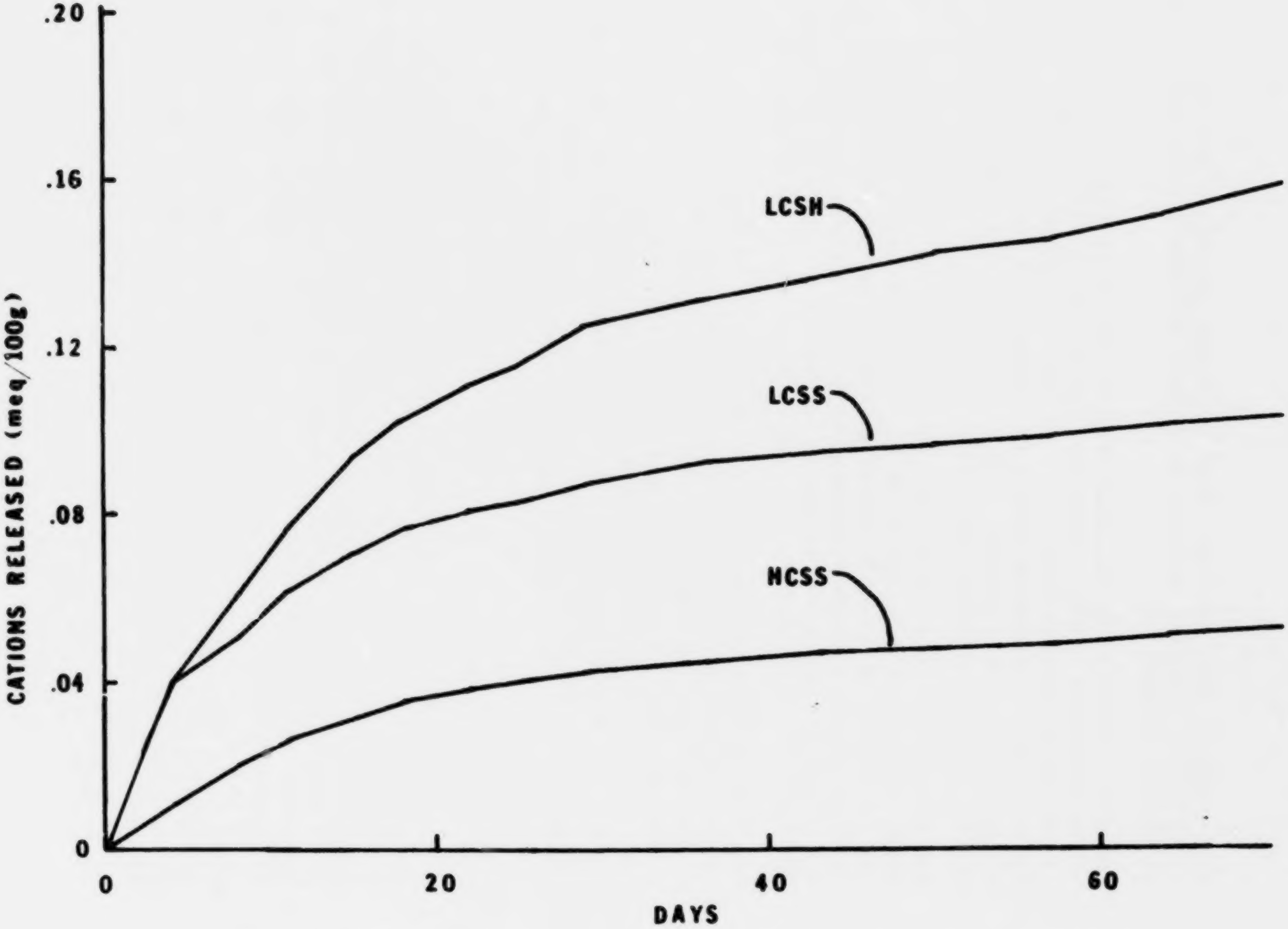

FIGURE 21. ACCUMULATIVE RELEASE OF POTASSIUM DURING SIMULATED WEATHERING OF THREE ROCK TYPES

percentage of total sulfur. Both low chroma sandstone and low chroma shale showed a steady increase in acidity produced at the end of the experiment (Figure 18).

The total amount of Fe released (Figure 19) was highest for the low chroma sandstone sample. Both the high chroma sandstone and low chroma shale released very little Fe, but in release of Al (Figure 19), the high chroma sandstone sample is highest with the low chroma sandstone being the next highest. This could be the result of the high chroma sandstone sampled being weathered.

The release of basic cations was as expected with the low chroma shale being highest in amount of Ca (Figure 20) and K (Figure 21). The low chroma sandstone released a large amount of both elements but the high chroma sandstone released only trace amounts; however, the low chroma sandstone was higher in release of Mg then the low chroma shale and the high chroma sandstone released the least (Figure 20).

The data in Table 20 indicate that the release of elements during weathering is slow. The low chroma sandstone had the fastest rate of weathering. This may seem contradictory to what has been previously stated but when comparing the amount released with the total amount of each element, it is quite evident that this is correct. The low chroma shale has a very slow release for all elements except Ca. The high chroma sandstone had the lowest total amount of all elements and the slowest release except for Al, which indicated a previous weathered condition.

General Observations

Observable disintegration of sandstones and shales in mine spoils indicates rock differences that are not fully understood. Some stones disintegrate quickly, whereas others that appear similar persist. Since secondary quartz growth is commonly evident, petrographically, it is likely that some resistant Lower Mahoning sandstone is effectively cemented with secondary quartz although cementation is not sufficient for classification as a quartzite.

Most shales that disintegrate readily are fine textured (clays), whereas the most resistant shales (or siltstones) contain higher proportions of silt and may be partially cemented either with carbonates or quartz.

Table 20

Comparison of three rock types in terms of total content of five cations and total release by simulated weathering.

	Meq/100 gm									
	Al		Fe		Mg		Ca		K	
Sample	Total	Released	Total	Released	Total	Released	Total	Released	Total	Released
High chroma sandstone	384.7	0.043	23.3	0.002	3.55	0.001	3.77	0.001	12.68	0.052
Low chroma sandstone	487.3	0.032	47.7	0.062	9.26	0.800	4.37	0.715	17.08	0.103
Low chroma shale	906.1	0.012	129.4	0.002	27.98	0.65	7.73	1.030	27.98	0.158

Freeze-thaw and wet-dry sequences or cycles and falling water drops have been used to separate sandstones and shales into groups differing in relative stability, but calibrations against field behavior in spoils have not yet been established.

Figures 22 and 23 illustrate evidences of rock weathering visible in fresh high walls. Figure 22 represents a typical exposure of Upper Freeport overburden with the dominant Lower Mahoning sandstone. Fragmentation of originally massive sandstone and unloading planes in the weathered zone are apparent, as is the brown high-chroma color depicted by the darker upper zone. The break between the unweathered and weathered sandstone is sharp in this illustration, as is the break between the sandstone and the approximately five feet of shale directly overlying the coal seam. The depth of the lower limit of the weathered zone coincides with the depth at which large changes in chemical composition occur as shown in Figures 8 and 16-21.

Figure 23 represents an exposure of materials, dominantly shale, overlying the Bakerstown coal seam. The change in color chroma from the weathered zone to the unweathered zone, although readily observed in the field, is less distinctly shown by photography. The lower limit of the weathered zone, approximately at the midpoint of the illustration, does however correspond to changes in rock composition indicated by laboratory analyses. The normally fissile shales also do not show the vivid unloading planes exhibited by weathering in massive sandstones, therefore, physical size and shape of rock fragments shows less variation in weathered and unweathered sections.

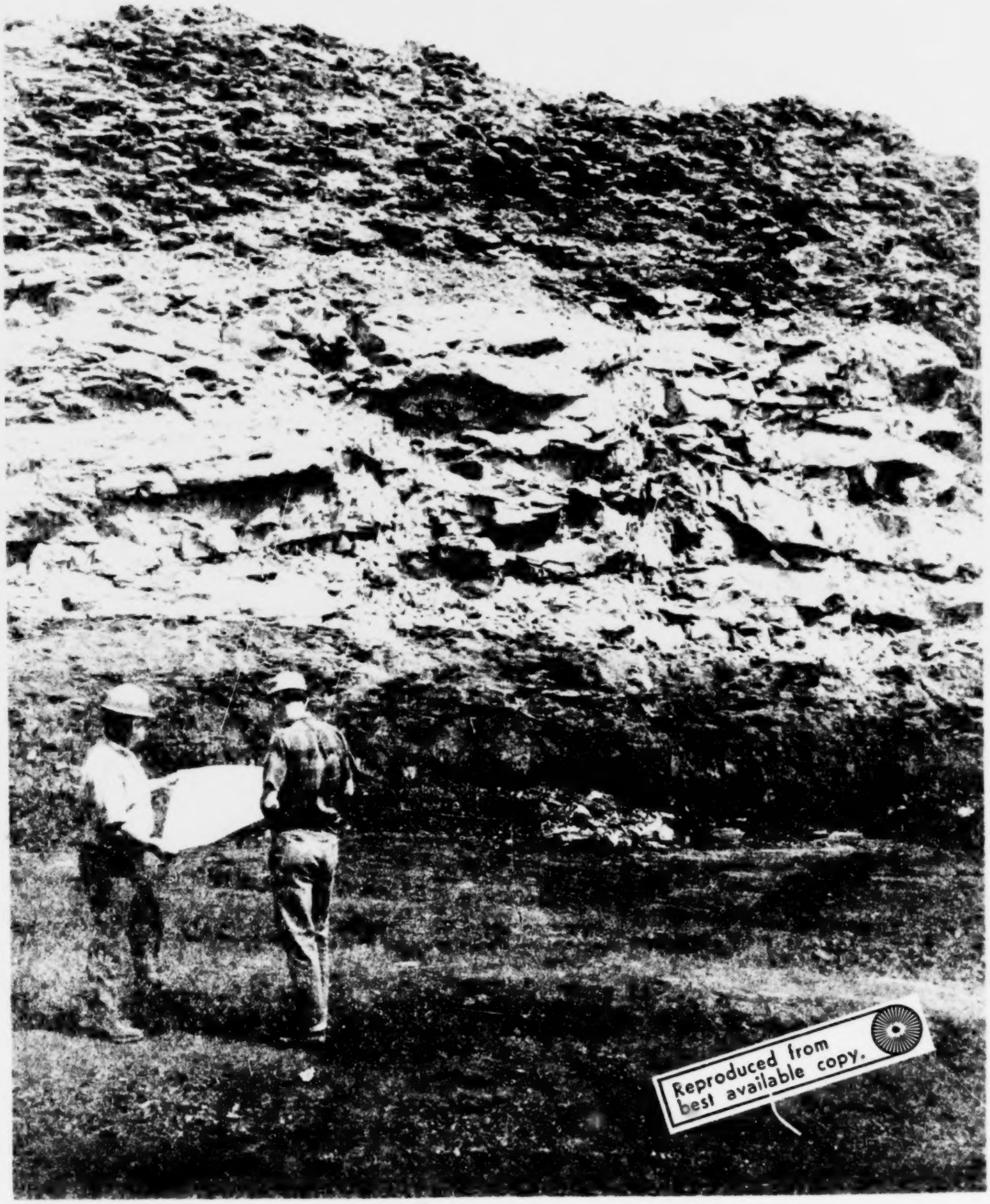

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FIGURE 22. FRESH EXPOSURE OF UPPER FREEPORT OVERBURDEN

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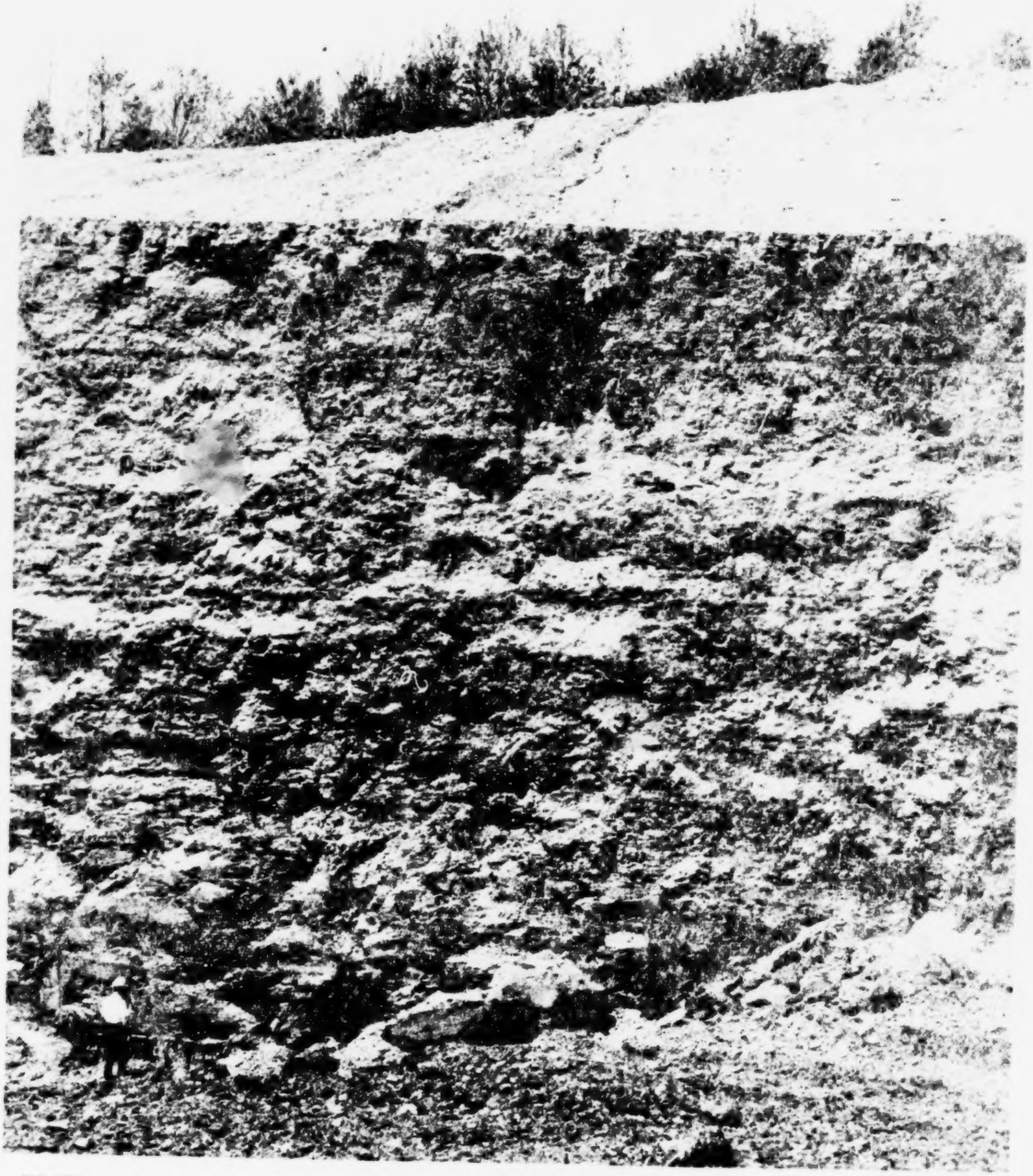

FIGURE 23. FRESH EXPOSURE OF BAKERSTOWN OVERBURDEN

SECTION XI

EVIDENCES FROM OLD MINE SPOILS

Barren Coal Spoils

The objectives of this phase of the project were to study certain old, barren spoils considered by the Soil Conservation Service to be difficult to vegetate; to isolate the problems; and to determine if there were any significant similarities between spoils resulting from the surface mining of the same coal horizon.

Bakerstown spoil, BK-1, (above Site P, Figure 7) was located in the Whetsell settlement one mile southeast of Caddell. The 17.3 acres (7 ha) stripped were graded in 1959, then limed, fertilized and planted twice to grasses and legumes. About 35% of the spoil is covered with vegetation, but sites selected for study were barren.

BK-2 was located near Site T (Figure 7), one mile northeast of Albright in Preston County. The spoil had been limed, fertilized and planted twice after it was graded in 1958, but both plantings failed.

The Pittsburgh spoils, P-1 and P-2, were located one mile (1.6 km) west of Smithtown in Monongalia County. P-1 is a 9.0 acre (36 ha) tract that was graded in 1964 and had an average pH of 3.8. It was relatively free of stones and had never been limed or planted. P-1 has a low highwall approximately 10 feet (3 m) high and the entire area has been severely weathered as evidenced by the rows of sand that line the bench.

P-2 was 6.7 Acres (2.7 ha) in size and had an average pH of 3.8 when graded in 1964. It has never been limed or planted. The highwall was approximately 30 feet high and intensely weathered as evidenced by the colluvial buildup at its base.

S-1, a spoil resulting from surface mining of the Sewickley coal horizon, was located two miles west of Westover in Monongalia County. It consisted of 6.5 acres (2.6 ha) of material that was relatively free of stones. The spoil was graded in 1962, at which time the pH averaged 3.8.

Sewickley spoil, S-2, was located 300 yards (275 m) diagonally across the road from S-1, and consisted of 3.2 acres (1.3 ha). The average pH was 4.6 when graded in 1965. It was scheduled for planting in 1966, but due to a drop in pH the planting was deferred.

UF-1 (Upper Freeport -1) was located two miles (3.2 km) south of Dellslow in the Morgan District of Monongalia County. The spoil had never been limed or planted and 80% of the 10.9 acres (4.4 ha) had a pH of 4.0 when graded in 1965. A covering of black shale was left on about 50% of the bench surface.

UF-2 was located in the Valley Point area of Preston County (Site D, Figure 7). The spoil was graded in 1960 and was extremely stony as well as quite acid, with a pH of 4.0. The 11.5 acres (4.6 ha) had not been limed or planted, but volunteer vegetation was slowly invading part of the outer slope.

An Ernest clay loam surface soil located near UF-1 in Monongalia County was sampled and included in the analyses since it is one of the most productive acid upland soils in this area. It was used for comparisons with mine spoils.

The chemical analyses performed were the standard procedures of West Virginia University Soil Testing Laboratory, except for the lime requirement which was done by direct Ca $(OH)_2$ titration, with 48 hours allowed for equilibration. An incubation of a 1:1 spoil:water suspension was used to determine if the pH of the spoil material would change with prolonged soaking. After five weeks, with pH determined weekly, there were no appreciable changes in pH, so the experiment was terminated.

Differences in chemical composition of spoils resulting from the surface mining of different coal horizons were notable (Table 21). The pH was similar and quite low, with the UF-2 having the highest and BK-2 having the lowest pH. The Bakerstown spoils were the highest in all nutrients and the Upper Freeport spoils were lowest in all nutrients except available K.

The Bakerstown spoils differed appreciably in the amount of nutrients present. BK-1 was low in P and Ca but medium in K and Mg. The mean pH was 3.0 with a standard deviation of 0.3. With a low pH and a low amount of Ca, it should be noted that Mg was quite high. An Ernest clay loam surface soil was low in Ca but was also low in Mg and the data in Table 1 show that the Ernest clay loam has about 12 times more Ca than Mg on a milliequivalent basis.

BK-2 was medium in P, K and Ca while testing high in Mg. The mean lime requirement was a ton more per acre than for BK-1 and the pH was 2.8.

Table 21

Chemical analyses of eight old mine soils and one surface soil in West Virginia.

Sample	pH Readings		Lime Requirement Tons/1000 Tons		pH Lbs/1000 Tons		K Lbs/1000 Tons		Ca Lbs/1000 Tons		Mg Lbs/1000 Tons	
	$\bar{x}$	S D	$\bar{x}$	S D	$\bar{x}$	S D	$\bar{x}$	S D	$\bar{x}$	S D	$\bar{x}$	S D
BK-1	3.0	0.3	3.29	0.85	30	6	101	46	180	131	169	30
BK-2	2.8	0.4	4.33	1.14	60	30	112	35	1640	2531	279	226
P-1	3.0	0.2	1.97	1.36	7	3	19	7	233	10	38	50
P-2	3.0	0.3	2.06	0.76	11	2	18	17	343	61	106	114
S-1	3.0	0.1	3.75	0.59	14	1	46	9	310	50	153	58
S-2	3.1	0.2	3.10	0.35	17	1	37	15	397	67	188	106
UF-1	3.0	0.7	2.00	1.02	15	3	49	12	80	36	20	5
UF-2	3.4	0.2	1.22	0.64	13	3	48	12	107	70	24	30
ERNEST	5.0	---	2.71	----	16	--	175	--	960	----	48	---

NOTE: Lime requirement by titration to pH 6.5. $\bar{x}$ is the mean of six replicates and S D is the Standard Deviation.

The tests for Mg and Ca and their large standard deviations from the mean indicates the heterogeneity of the spoil material. The unusually large amounts of Mg on BK-1 and 2 indicates the need for more intensive study of the chemical properties of these spoils.

The Sewickley spoils showed close agreement in all analyses. The interesting aspect again was the amount of Mg contained in material that had such a low pH. The Pittsburgh spoil, P-2, exhibited this same characteristic.

The Upper Freeport spoils differed in pH and lime requirement and were very low in all nutrients (Table 21). They only compared favorably to the Ernest clay loam in available P but even this was very low. Only BK-1 and BK-2 compared favorably with the Ernest clay loam in all nutrients although several spoils contained higher amounts of Mg.

Smith et al. (1971), compared the bulk density of iron-ore spoils to the bulk density of adjacent natural soils. The mean bulk density of the natural surface soils was 1.02 g/cc. Using this bulk density and that of Ernest clay loam as a standard, comparisons were made with the strip mine spoils studied.

The uncorrected bulk densities indicated small differences between the mean bulk density of spoils resulting from the same coal horizon (Table 22). Only the Upper Freeport spoils differed appreciably. All spoils had higher mean bulk densities than the bulk density of natural soils. Excluding the material 6.35 mm (0.25 inch) brought the mean bulk densities into closer agreement with the mean bulk density of natural surface soils.

The particle size data in Table 22 indicates the effects of weathering. Large differences between the Sewickley spoils in the particle size distribution cannot be explained by the effects of erosion since S-2 was more highly eroded than S-1.

The Bakerstown spoils were in close agreement in their particle size distribution.

Most of the material on all spoil areas was found in the 2 mm (0.08 inch) fraction. The next largest amount of material was in the 6.35 mm (0.25 inch) fraction. The Pittsburgh spoils showed the highest degree of physical weathering with over 64% of the material being 2 mm (Table 22).

Table 22

Bulk density, coarse particle size analysis and textural analysis for 8 spoils.

	Bulk Density				Particle Size Analysis				Textural Analysis			
Sample	Actual g/cc		Corrected g/cc		>6.35 mm %	2-6.35 mm %	<2 mm %		0.05-2 mm %	0.002-0.05 mm %	<0.002 mm %	
	x	S D	x	S D	x	x	x	S D	x	x	x	S D
BK-1	1.47	0.10	1.25	0.11	28.0	34.0	37.8	9.0	23.2	46.6	30.2	4.1
BK-2	1.42	0.12	1.22	0.16	25.0	37.5	39.1	8.3	20.3	44.1	35.7	13.2
P-1	1.52	0.12	1.36	0.13	21.2	13.4	65.4	17.8	64.1	21.9	14.0	3.4
P-2	1.49	0.10	1.39	0.04	15.9	21.2	62.9	15.6	56.1	25.2	18.7	6.6
S-1	1.45	0.17	1.17	0.10	32.8	30.1	37.0	10.4	36.4	40.3	23.3	2.2
S-2	1.41	0.05	1.31	0.04	14.7	25.7	49.7	12.8	31.7	44.5	23.7	2.7
UF-1	1.38	0.16	1.13	0.10	30.5	22.8	46.7	18.1	60.5	20.1	19.3	10.3
UF-2	1.60	0.18	1.34	0.16	32.4	16.2	51.4	15.3	68.3	18.2	13.5	5.3
ERNEST	1.12	0.01	1.12	0.01	----	----	----	----	29.8	40.0	30.2	3.4

NOTE: Corrected bulk densities apply to the fraction finer than 6.35 mm. S D means Standard Deviation.

The Sewickley spoils were relatively uniform and the two means agreed closely in the percentages of each soil separate. They were both classified as loam soils.

The Pittsburgh spoils were similar in the textures found at each site on the two spoils. The textures for each were sandy loam, although the mean percentages of the soil separates on each area differed considerably. Two samples from P-2 were sandy clay loams, but this was due to an alluvial deposit at this site.

The Freeport spoils were both sandy loams and the individual samples from each were in close agreement except for two samples and UF-1. These were taken on a slope of approximately 10% at a point about 25 feet from the base of the highwall. Evidently, they contained fine material that was being washed down the slope.

Textures of the Bakerstown spoils were relatively variable, but the mean of each was a clay loam. The standard deviations indicated the heterogeneity of spoil material subjected to severe weathering and erosion.

Table 22 shows certain trends in spoil physical properties resulting from strip mining of different coal horizons. Bulk densities calculated to exclude coarse 6.35 mm (0.25 inch) fragments reduced some variances. The volume and weight of the 6.35 mm (0.25 inch) material was subtracted from the total weight and volume of each sample and then the corrected bulk density was calculated on the remaining weight and volume of each sample. The Pittsburgh spoils had 15.9% and 21.2% respectively of material 6.35 mm (0.25 inch), whereas the other spoils, except S-2, had more material in this size range. This indicated that fines of the Pittsburgh spoils were more compacted than the other spoils.

The particle size analyses showed that the Pittsburgh spoils had a greater percentage of the 2 mm (0.08 inch) material than the other spoils. They were the only spoils with 60% of the material in the 2 mm (0.08 inch) fraction. Using this as a measure of weathering, the Pittsburgh spoils had weathered more rapidly than the others. This does not imply that the Pittsburgh spoils will eventually develop into the best soil for supporting vegetation.

Considering the textural analyses of the 2 mm (0.08 inch) fraction, it is evident that the Pittsburgh and Upper Freeport spoils will become sandy soils. This is a result of the sandstone parent material. The Sewickley spoils exhibited a loam texture.

Total porosity is presented as 0 bar tension in Table 23. All spoils were low in total porosity compared to an Ernest clay loam surface soil, primarily because of coarse fragments. At the 1/3 bar tension, all Bakerstown and Upper Freeport spoils agreed more closely, but the Pittsburgh and Sewickley spoils differed more than for 0 tension.

The differences in water holding ability between P-1 at the 1/3 bar tension can be explained by the 4% difference in the amount of clay between the two areas. The differences between the two Sewickley spoils cannot be explained on the same basis. This difference remained as the tension was increased to 1 bar, but at the 15 bar tension most of the differences were minimized.

In spoils, the available water (water capacity above that held at the 15 bar tension) at 0 bar tension approached the available water stored in the Ernest clay loam at zero tension. There was only 0.3% difference between UF-2 and the Ernest at zero tension, but as the tension was increased to 1 bar only BK-1, P-2 and S-2 approached the amount of moisture that was held by the Ernest clay loam.

All spoils had rapid drainage capacity (i.e., porosity drained at 1/3 bar) with the Bakerstown spoils having the slowest and the Upper Freeport spoils having the fastest. All spoils would have "gravelly" or "stony" modifying their textural names if they were to be described like soils. Kohnke (1968) has suggested textural relations to available water as follows:

> "Field capacity and wilting point determine the maximum amount of available moisture in the soil. These amounts vary from 5% of the total volume for gravelly soils and 10% for sandy soils to 15 and 20% for loams, silt loams and clay loams."

A favorable comparison can thus be drawn between the available water found on the eight spoils and gravelly or sandy soils which should have 5 to 10% of the total volume as available water. In fact, the spoils, except for UF-1, had more available water at the 1 bar tension than the norm for gravelly soils, although the 1/3 bar tension is considered a closer approximation of field capacity.

Additional details about old barren coal spoils are being published elsewhere (Sobek and Smith, in press, 1971).

Table 23

Moisture retention on a volume basis at four tensions and available water by volume in percent and inches per foot of depth.

Sample	Moisture Retention				Available Water					
	0 Bar	1/3 Bar	1 Bar	15 Bar	0 Bar		1/3 Bar		1 Bar	
	%	%	%	%	%	inches	%	inches	%	inches
BK-1	44.5	19.3	17.1	8.7	35.8	4.30	10.6	1.27	8.4	1.01
BK-2	46.4	19.9	17.5	11.3	35.1	4.21	8.6	1.03	6.2	0.74
P-1	42.6	14.2	11.2	4.1	38.5	4.62	10.1	1.21	7.1	0.85
P-2	43.8	20.0	15.6	6.3	37.5	4.50	13.7	1.64	9.3	1.12
S-1	45.3	16.1	13.2	7.2	38.1	4.57	8.9	1.07	6.0	0.72
S-2	46.8	21.9	17.3	8.7	38.1	4.57	13.2	1.58	8.6	1.03
UF-1	47.9	11.4	10.4	5.8	42.1	5.05	5.6	0.67	4.6	0.55
UF-2	39.6	12.8	10.3	4.4	35.2	4.22	8.4	1.01	5.9	0.71
ERNEST	56.4	32.0	26.8	14.0	42.4	5.09	18.0	2.16	12.8	1.54

Vegetated Coal Spoils

Some surface mine spoils resulting from operations during World War II have exhibited remarkable vegetative cover since reclamation. An area left barren after recovery of the Pittsburgh coal near Canyon, Monongalia County, in 1943, and treated as a test plot by the Agricultural Experiment Station in 1944 was selected for follow-up studies under the project reported here. The investigation in 1944 determined that the Canyon spoil was "very strongly to strongly acid" and represented an area that was quite toxic to vegetation (Tyner and Smith, 1945). These investigators found that the five tons per acre of limestone that was applied, followed by a second application 2 years later was sufficient to establish a good stand of many different forage species. Combinations of N, P, K fertilizers and manure aided establishment of cover. As far as could be determined, no follow-up fertilization program was carried out; however, the landowner has used the spoil as a pasture, and the present vegetative cover as well as total nitrogen have been influenced by the animal manure.

Table 24 presents some chemical properties of the spoil as found during recent study. The nitrogen percentages and total quantities accumulated during 26 years are comparable with natural cultivated soils of this area. Analyses for total sulfur indicate enough sulfur to create excessive acidity and toxicity if present as reactive pyrite. However, considerable coal is present in the spoil, indicating that the remaining sulfur is likely in organic form and is not converted to mineral acid until the coal is destroyed by oxidation. The spoil pH appears to be barely high enough for the more tolerant forage species to survive; better growth could be obtained if lime was applied to the present pasture. Site 1, with pH below 4.0 has only very sparce vegetative cover, but it is protected from erosion.

Iron Ore Spoils

Sites and Experimental Procedures

Sites included in the study were as follows: Three units, Chestnut Ridge, Quarry Run and Johnson Hollow are located in Coopers Rock State Forest in northeastern Monongalia County, West Virginia. The spoil source consisted of dark gray and brown shales derived from the Pottsville group of the Pennsylvanian system. The age of these spoils is estimated to be between 85 and 130 years. An additional three units, Glen, Massey and Peters occur in the Gladesville area of western Preston County, West Virginia, about 12 miles (19 km) southeast of Morgantown. These spoils are estimated to be between 70 and 85 years old.

Table 24

Properties of 26 year old vegetated Pittsburgh mine spoils.

Site	Depth (in)	pH (1:1)	Approx. Bulk Density	Nitrogen (%)	Sulfur (%)	Nitrogen lbs/Acre
I	0-1	3.7	0.72	0.44	0.475	709
	1-2	3.4	1.00	0.22	0.755	498
	2-3	3.5	1.10	0.18	0.265	436
	3-4	3.8	1.20	0.12	0.185	340
	4-5	3.7	1.32	0.80	0.120	252
	5-6	3.5	1.33	0.05	0.080	144
					TOTAL	2379
II	0-1	4.6	0.72	0.38	0.355	619
	1-2	4.6	1.00	0.15	0.190	340
	2-3	4.4	1.10	0.12	0.360	299
	3-4	4.2	1.20	0.10	0.080	272
	4-5	4.4	1.32	0.11	0.085	330
	5-6	4.4	1.33	0.11	0.100	330
					TOTAL	2190
III	0-1	4.8	0.72	0.47	0.420	766
	1-2	4.7	1.00	0.28	0.390	634
	2-3	4.5	1.10	0.17	0.465	423
	3-4	---	1.20	0.15	0.320	408
	4-5	4.2	1.32	0.11	0.093	330
	5-6	4.1	1.33	0.13	0.425	390
					TOTAL	2951

Relative water intake rates by dry and wet spoil and contiguous soil were determined at the Peters, Quarry Run and Johnson Hollow units as follows: At 5 points at each site, forest litter or grass sod was removed from the spoil or soil surface and a core 3 3/4 inches (9.5 cm) in diameter and 2 inches (5 cm) long was removed. In the resulting hole, the amount of water required to maintain a constant depth of 1 inch for 15, 30, 60 and 120 minute intervals was measured. Such measurements provided dry intake rate data. The area around each hole was then saturated with water and, after one hour, the water intake of the wet spoil and soil was determined as before. Actual intake rates were calculated in terms of acre-inches of water per unit of core area.

Mineralogy of Chestnut Ridge spoil and B horizons of contiguous soils was studied by standard processing and X-ray diffraction procedures.

Moisture tension changes were determined periodically (usually weekly) during 4 growing seasons on paired spoil and soil sites at two locations, one north facing and one south facing, under woodland. Measurements were made with plastic impregnated gypsum resistance blocks (Bouyoucos type) imbedded at different depths in profiles. Moisture tension values so obtained are relative.

Statistical significance of differences between adjacent means in the several means was tested by standard analysis of variance. Levels of significance were calculated, using F and LSD tests.

Bulk Density

Table 25 shows comparisons for 6 units. The bulk density means for iron ore spoil were significantly greater than those of contiguous soils. For comparisons with typical surface coal mine spoil from three prominent coals now being mined in northern West Virginia, Table 26 is provided. The low value for sample number 7 (Canyon) is due to the presence of loose, fine coal particles.

Particle Size

Tables 27 and 28 include coarse particles as well as fine separates. These data provide a test at 2 units as to whether near-surface weathering and soil formation have caused major changes since spoil deposition. Coarse particles (>2 mm) averaged 60% by weight for Peters and 43% for Chestnut Ridge, which are higher than normally found in Gilpin, Dekalb and related surface soils.

Table 25

Bulk densities of near-surface spoil and associated surface soils.

Neighborhood	Unit	Bulk Density Spoil	Soil	Calculated Porosites Spoils	Soil
		gms/cc	gms/cc	%	%
Coopers Rock	Chestnut Ridge	1.48	0.90	44	66
Coopers Rock	Quarry Run	1.52	1.13	43	57
Coopers Rock	Johnson Hollow	1.42	0.90	46	66
Gladesville	Glen	1.39	1.01	48	63
Gladesville	Massey	1.58	1.12	40	58
Gladesville	Peters	1.41	1.13	47	57
Mean		1.47	1.03	45	61

NOTE: Each value is the mean of 4 replicates.

Table 26

Bulk density in grams per cc for spoil from surface mining of coal at 3 selected locations.

Sample No.	Canyon Monongalia Co. Pittsburgh Coal	Arthurdale Preston Co. Upper Freeport Coal	Kingwood Preston Co. Bakerstown Coal
	gms/cc	gms/cc	gms/cc
1	1.612	1.634	1.430
2	1.638	1.772	1.518
3	1.633	1.815	1.010
4	1.396	1.723	1.546
5	1.393	1.691	1.342
6	1.583	1.663	1.274
7	0.963	1.875	1.238
8	1.481	1.751	1.449
9	1.439	1.579	1.437
10	1.664	1.692	1.253
Average	1.480	1.719	1.350

Table 27

Mean particle size distribution including coarse fragments for the Chestnut Ridge spoil.

Depth inches	Coarse Fraction >2.0 mm percent	Sands 2.0 to .05 mm percent	Silt .05 to .002 mm percent	Clay <.002 mm percent
0-1	56.8	18.0	17.8	7.4
1-2	59.3	16.2	15.5	9.0
2-3	48.5	18.1	19.8	13.6
3-4	47.2	22.0	18.3	12.5
4-5	45.7	21.8	18.9	13.6
5-6	35.5	24.5	22.2	17.8
6-7	29.9	24.7	23.9	20.5
7-8	41.8	19.4	21.3	17.5
8-9	40.7	18.1	22.6	18.6
9-10	46.8	16.1	20.4	16.7
10-11	31.7	23.5	25.4	19.4
11-17	34.7	21.0	25.0	19.3
17-23	42.2	18.3	21.3	18.2
Mean	43.1	20.1	21.0	15.6

NOTE: Each value is the mean of 8 replicates.

Table 28

Mean particle size distribution including coarse fragments with depth for the Peters spoil.

Depth inches	Coarse Fractions >2.0 mm percent	Sands 2.0 to .05 mm percent	Silt .05 to .002 mm percent	Clay <.002 mm percent
0-1	47.2	14.9	29.6	8.3
1-2	47.7	15.7	25.4	11.2
2-4	53.3	12.9	21.4	12.4
4-6	58.3	10.3	18.6	12.8
6-8	64.8	8.7	15.2	11.3
8-11	61.1	9.7	17.0	12.2
11-14	64.2	9.3	16.7	11.6
14-17	66.2	8.2	14.7	10.7
17-20	69.1	7.6	13.2	10.1
20-23	66.4	7.9	14.9	10.8
Mean	59.8	10.5	18.7	11.1

NOTE: Each value is the mean of 8 replicates.

Mean percentages of coarse particles in the spoils were not significantly influenced by depth to 23 inches (58 cm). Apparently, intensity of weathering near the surface has not been sufficient to significantly reduce coarse particle percentages (Tables 27 and 28).

Nitrogen and Organic Matter

Summary nitrogen data for the 6 inch (15 cm) depth are given in Table 29. The nitrogen content of spoil, although it was always lower than in contiguous soils, varied from 82% to 97% of that in adjacent soil. Approximate average rates of increase varied from 18 to 31 pounds per acre (20 to 35 kg/ha) annually. On the Peters and Massey spoils, white clover could account for part of the nitrogen accumulated.

Appreciable nitrogen continued downward in spoil at least to a depth of 23 inches. Amounts found in Peters spoil below 6 inches were similar to undisturbed soils in this region (Jencks, 1969).

Acidity (pH)

Differences in pH with depth (Tables 30 and 31) were not consistent enough for statistical significance. Differences in original rock composition would account for moderate, random pH variations at each of the 2 locations, and for the mean difference of 0.8 units between the 2 locations.

Except for a few extremely low values in the Chestnut Ridge spoil, pH's in the iron ore spoils were similar to those in Dekalb and Gilpin soils. The 6 extremely low pH values recorded for Chestnut Ridge spoil may reflect the presence of significant quantities of pyrite in the rock, similar to some coal overburdens.

Cation Exchange and Exchangeable Bases

Cation exchange capacities, exchangeable bases and related data are presented in Table 32. Cation exchange capacities and levels of exchangeable bases were lower in the top inch of spoil than in Dekalb and Gilpin soils. Below 4 or 5 inches in spoil, cation exchange capacities, exchangeable base levels and base saturation were higher in spoils than in a comparable depth in soils. Higher values in the top inch of soils is associated with organic matter.

Table 29

The nitrogen content of spoil versus associated soils.

Unit	Nitrogen/acre (6-inch depth)		Significance of treatment difference	Dominant present vegetation	Probably dominant vegetation over time	Estimated age (years)	Approx. acre increase annually in spoil pounds
	Spoil pounds	Soil pounds					
Chestnut Ridge	2,430	2.844	HS	Forest	Forest	85-119	23
Glen	2,533	3,105	HS	Forest	Forest	72-83	31
Johnson Hollow	1,900	2.046	NS	Forest	Forest	85-131	18
Massey	1,756	2,069	S	Grass	Grass	72-83	23
Peters	2,438	2,765	S	Grass	Grass	72-83	31
Quarry Run	2,520	2,596	NS	Forest	Forest	85-119	25

NOTE: Each value is the mean of 4 replicates.

Table 30

Profiles (pH) of Peters mine spoil in grass pasture near Gladesville.

Depth Inches	Pit Designations								
	1A	1B	2A	2B	3A	3B	5A	5B	Mean
0-1	6.05	5.85	5.55	5.90	6.00	5.75	5.00	5.45	5.69
1-2	5.15	5.45	4.85	4.90	5.75	5.45	5.20	5.15	5.24
2-4	5.15	5.25	4.95	4.80	5.75	5.40	5.00	5.20	5.19
4-6	5.15	5.10	4.95	4.82	5.50	5.40	4.95	5.20	5.13
6-8	5.15	5.10	4.90	4.70	5.45	5.25	4.90	5.10	5.07
8-11	5.20	5.05	4.80	4.70	5.45	5.10	5.00	5.20	5.06
11-14	5.15	5.10	4.80	4.78	5.50	5.20	5.00	5.20	5.09
14-17	5.05	5.15	4.75	4.80	5.40	5.25	5.15	5.05	5.07
17-20	5.10	5.15	4.75	4.75	5.30	5.10	5.05	4.85	5.01
20-23	5.10	5.25	4.70	4.70	5.40	5.05	5.00	4.95	5.02
Mean	5.22	5.25	4.90	4.88	5.55	5.30	5.02	5.13	5.16

Table 31

Profiles (pH) of Chestnut Ridge mine spoil in forest.

Depth Inches	Profile Number 1A	1B	2A	2B	3A	3B	4A	4B	Mean
0-1	4.23	4.62	4.42	4.28	4.26	4.25	4.36	4.21	4.33
1-2	4.08	4.32	4.15	4.24	4.30	4.62	4.50	3.85	4.26
2-3	4.15	4.40	4.40	4.27	4.49	4.62	4.42	4.50	4.41
3-4	4.13	4.60	4.60	4.35	4.55	4.51	4.38	4.45	4.45
4-5	4.24	4.50	4.60	4.41	4.66	4.30	4.23	4.52	4.43
5-6	4.20	4.34	4.64	4.50	4.76	3.80	4.34	4.52	4.39
6-7	4.24	4.41	4.66	4.60	4.12	4.41	4.23	4.44	4.39
7-8	4.31	4.38	4.60	4.59	4.89	4.60	4.16	4.55	4.51
8-9	4.35	4.42	4.55	4.60	4.80	3.10	4.20	3.85	4.23
9-10	4.35	4.50	4.60	4.30	4.78	4.88	4.51	4.20	4.51
10-11	4.30	4.95	4.62	4.65	4.92	5.06	4.18	4.45	4.64
11-17	4.40	4.81	4.46	4.65	3.16	5.10	4.25	3.99	4.35
17-23	4.60	4.65	4.48	4.60	5.07	4.99	4.44	4.31	4.65
Mean	4.28	4.53	4.52	4.46	4.52	4.48	4.32	4.30	4.42

Table 32

Summary of cation-exchange and related characteristics of spoil and of the A and B horizons of contiguous soils.

	Depth	Soil Horiz.	Total <2.0mm material	pH	Organic carbon	<2μ clay	Cation-exchange capacity	Exch. Ca	Exch. Mg	Exch. K	Base Satur.
					Peters Unit						
	in.		%		%	%	me/100 g	me/100 g	me/100 g	me/100 g	%
Spoil	0-6	A_1	70	5.4	2.0	11.0	11.6	3.08	0.96	0.19	36.5
Soil	0-1	Ap_1	64	5.0	6.4	6.9	23.3	8.32	1.81	0.36	45.0
Soil	1-4	Ap_2	78	4.8	4.1	10.5	14.0	1.79	0.91	0.17	20.5
Soil	4-5	Ap_3	78	4.9	2.6	12.1	11.3	1.71	0.36	0.14	14.8
Soil	5-10	B_1	72	4.8	1.4	13.7	7.8	1.00	0.26	0.09	17.3
Soil	10-18	B_2	55	4.3	0.3	16.0	5.1	0.94	0.13	0.07	22.4
					Chestnut Ridge Unit						
Spoil	0-6	A_1	66	4.3	1.8	12.3	6.80	0.66	0.33	0.13	16.5
Soil	0-1	A_1	51	4.11	6.4	7.4	13.7	0.97	0.31	0.16	10.5
Soil	1-5	A_2	50	4.62	2.0	8.6	6.9	0.25	0.08	0.11	6.4
Soil	5-8	A_3	48	4.62	1.2	8.9	4.6	0.19	0.10	0.09	8.3
Soil	8-18	B	60	4.42	0.7	14.5	4.4	0.27	0.08	0.09	10.0

Table 33

Accumulated acre-inches water intake of spoil and adjacent soil.

Time	Peters Unit				Johnson Hollow Unit				Quarry Run Unit			
	Spoil		Soil		Spoil		Soil		Spoil		Soil	
Mins.	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
15	2.4	2.8	3.8	6.2	6.0	1.9	8.4	3.7	6.4	3.51	10.4	3.2
30	3.2	4.4	6.2	11.7	9.4	2.7	14.3	5.4	10.6	5.83	16.7	6.1
60	4.7	8.0	11.1	22.4	15.4	4.3	25.5	9.7	18.6	11.4	27.0	11.0
120	8.0	15.0	22.0	42.1	25.0	7.8	42.6	18.2	31.1	20.4	43.0	17.7

Table 34 (continued)

	Mica	Kaolinite	Vermiculite	Quartz	Unknown
Coarse Clay (2-0.2 micron)	2	2	2	2	1
Fine Clay (<0.2 micron)	2	2	2	1	-
Peters (Gladesville) Normal Sub-soil					
Assumed Parent Material	2	2	-	2	-
Silt	2	2	1	3	-
Coarse Clay (2-0.2 micron)	3	3	3	2	1
Fine Clay (<0.2 micron)	2	2	2	1	1

Key: 3 = Abundant; - = Absent

Mineralogy

Ratings for 2 units obtained by standard X-ray diffraction techniques (Jackson, 1956) are given in Table 34. The clay-size (<2 micron) fraction of rock fragments assumed to be parent material of the iron ore spoil contained no vermiculite or other 14 angstrom minerals. Mica, kaolinite and quartz were, however, present in all samples. In the fine separates of both spoils and subsoils, vermiculite appeared and was prominent in the clay and fine clay (<0.2 micron) fraction of subsoils and in Peters spoil. Mica was absent in Chestnut Ridge fine clay whereas vermiculite was prominent. These results are in accord with the theory that micas in parent material weather to vermiculite. Similarity of the mineralogy in the comparatively young Peters spoil and contiguous mature (Gilpin) subsoil, both under pasture, suggests that Peters mineralogy may be inherited from disintegration of parent rock. The disappearance of mica in Chestnut Ridge (Dekalb) normal subsoil but not in spoils reflects the much longer time involved for normal, mature soil formation than occurred since exposure of the iron ore spoils. Persistance of mica in Peters (Gilpin) subsoil may be related to the higher pH inherited from slightly calcareous shales.

Infiltration, dry and wet

Dry and wet water infiltration data for iron ore spoil and adjacent soils are summarized for 3 units in Table 33. Considerable variation occurred but replication established higher final infiltration rates for soil than for spoil, at the Peters and Johnson Hollow units. Also, both wet and dry cumulative intake at these 2 units were higher for soils than for spoils. No difference between spoil and soil was found at the Quarry Run unit. The higher water intake by soils is related to the subangular blocky structure in natural subsoils in contrast to the massive matrix of weathered shaly spoil.

Field Moisture Trends and Rainfall

Field moisture tension measurements taken during 4 growing seasons showed that retention of moisture down to 1 foot (30 cm) was similar in both spoils and soils. During low rainfall seasons, spoils held more plant available moisture below 2 to 3 feet (60 to 90 cm) than soils, a factor important to deep-rooted plants. Even when rainfall was normal and the moisture retention below 2 to 3 feet in soils was adequate, spoil material held more reserve moisture.

Root Distribution and Development

Soil profiles terminated with bedrock at about 33 inches (84 cm), whereas spoil material was deeper, thus allowing deeper penetration of roots. Approximately 95% of the plant roots in soil was found in the top 24 inches (64 cm), whereas in spoil only about 57% was found in this depth with the remainder being distributed throughout to a depth of 72 inches (183 cm). Root numbers were higher in spoils than in soils, 1012 in spoils (to 72 inches) as compared to 720 in soils (to bedrock). Few roots were found below 72 inches in spoils.

Forest Site Quality Ratings

Forest site quality comparisons show that there were no consistently significant differences between spoils and natural soils during the time represented. It must be considered that these old spoils now contain nitrogen and organic matter that have accumulated gradually because of tree establishment, a soil productivity factor that was not originally present.

Topography, Erosion, and Drainage Water Quality

Gradients of Quarry Run and Johnson Hollow are between 300 and 500 feet per mile (56 and 94 m per km). Water flow is rapid and fine particles are continually being removed leaving pebbly Pottsville sandstone exposed to scouring. If any mine spoil eroded into these channels, it was carried downstream into Cheat River. Normal flow was found to be free of sediment. Water samples collected at near-normal flow were clear, with pH of 6.3 and very low in soluble salts (100 ppm). Iron and nitrogen contents were very low (1.0 ppm). Sulfate level was low (16 ppm).

The Gladesville area drains into Brains Creek, upper reaches of which have low gradients where this small stream is perched on erosion-resistant sandstone. Below the iron ore spoils, there is no evidence of sediment eroded from spoils. Samples from spoil seepage and run-off were clear, with pH of 5.6 and very low soluble salts (less than 100 ppm). Iron, nitrogen, and sulfate contents were very low.

Additional details about old iron ore spoils are being published elsewhere (Smith, Tryon and Tyner, 1971).

Summary

Samples from old spoils that have remained barren for 5 to 10 years indicated acidity (pH 3.5) was the primary influence preventing revegetation. Nutrient levels ranged from very low to medium with highest quantities of nutrients in Bakerstown spoils.

Bulk densities, coarse fragments, textures and water retention capacities indicated ranges which should accommodate plant growth, although drouthiness would be expected with the most sandy and stony spoils, especially with shallow rooting species.

Twenty-five year old spoils near Morgantown (Canyon) from surface mining of Pittsburgh coal are satisfactorily covered with forage grasses and legumes and contain near normal percentages of soil organic matter, although analyses for total sulphur indicated 0.5 to 1.2%. This is enough sulphur to create excessive acidity and toxicity if present as reactive pyrite. However, considerable coal is present in the spoil, which probably means the sulphur remaining is in organic forms and is not converted to mineral acids until the coal is destroyed by oxidation.

Iron ore spoils of shaly lower Pennsylvanian, moderately acid materials, abandoned 70 to 130 years prior to sampling provided evidences that the natural soils were superior in bulk densities (lower), porosity (higher), soil structure development, infiltration, nitrogen or organic matter, surface texture (more loamy), and smoother land surfaces. On the other hand, mine spoils were superior in depth for plant rooting, total available water holding capacity, certain plant nutrients, and gentler slopes on benches. Forest site quality, pH and soil mineralogy were not greatly different between natural soils and mine spoils.

SECTION XII

MICROBIOLOGICAL INTERACTIONS

The chemoautotrophic bacteria *Thiobacillus ferroxidans*, *Thiobacillus thiooxidans* and *Ferrobacillus ferrooxidans* have been isolated repeatedly from acidic coal mine effluents. Of these, *Ferrobacillus ferrooxidans* and *Thiobacillus ferrooxidans* are probably the most important species in promoting the formation of the acidic drainage. These organisms have been isolated not only from bituminous coal deep mine effluents, but also from drainage from surface mine operations (Singer and Stumm, 1970). The organisms have been shown to be capable of oxidizing the sulfide ores pyrite and/or marcasite (Beck and Brown, 1968) with the evolution of considerable quantities of sulfuric acid and soluble iron which eventually precipitates as ferric hydroxide also known commonly as "yellow boy." The organisms involved obtain energy for cell growth through such oxidations; the carbon for cell growth is obtained from atmospheric CO_2, hence the term chemoautotroph.

Thiobacillus thiooxidans is incapable of oxidizing the iron disulfides and as such plays a minor role in the oxidation of the sulfide ores. The organism is readily grown on elemental sulfur or thiosulfate.

Ferrobacillus ferrooxidans has recently been proven capable of growth on several sulfuritic materials. At present there is some controversy as to whether or not *Ferrobacillus ferrooxidans* should be designated a separate species from *Thiobacillus ferroxidans*. Whatever the outcome, it is still evident that the organisms remain prominent in the formation of acid mine drainage.

Several of the surface mine spoil materials (also known as overburden) have been shown by chemical, physical, and microscopic analysis to contain pyritic material. Pyrite has been observed in sandstone strata, shale strata and also in the coal itself. The pyrite as such in these materials makes them susceptible to microbial attack by the previously mentioned chemoautotrophic bacteria with the subsequent production of acidic end products. It is the acid-producing nature of these spoil materials which necessitates the use of some precautions in replacement if reclamation is to be successful.

Experimental Methods

Effect of Buried Depth on the Oxidation of Pyrite

For this study, columns of plastic pipe 48 inches (122 cm) high with 6 inches (15.2 cm) inside diameter were employed. The columns were filled with a soil obtained at Site A. This soil was described and identified as a Dekalb loam, thin variant (Appendix B). Chemical and mineralogical information about this soil is included in Section IX. Mineralogy of this soil is "mixed" by soil survey terminology. However, quartz dominated the sand and silt fractions, and kaolinite is the most abundant clay species. A 1/8 inch (3 mm) layer, 6 inches (15.2 cm) in diameter, of pyritic material was placed in each of six columns at a specified depth. The depths included were "surface" (1/2 inch (1.3 cm) below soil surface), 3 inches (7.6 cm), 6 inches (15 cm), 1 ft. (30 cm), 2 ft. (61 cm), and 3 ft. (91 cm) subsurface. A seventh column containing no pyritic material was included as a control. The pyrite used ranged from 0.25 mm to 1 mm in particle size, and was placed in a uniform layer over the complete area of the inside of column at the specified depths.

Beneath the pyritic monolayer a funnel packed lightly with glass wool was installed to collect leachate from the immediate area of the reaction site. The funnel was connected to the outside of the column through a short length of surgical tubing attached to a 1/4 inch (6.4 mm) diameter plexiglass tube fixed through the cylinder wall. One liter of distilled water was applied to the surface of each cylinder at two-week intervals; approximately 850 ml of this was recovered. Drainage from the funnels was collected in two-hole stoppered 250 ml Erlenmeyer flasks connected to the plexiglass drain tube by a short length of Tygon tubing. Evaporation was minimal. Remaining drainage passed through the length of the column for collection and analysis.

All analyses (Fe^{++}, Fe total, SO_4) were performed using the HACH AC-DR colorimeter, with the exception of pH which was measured using a Beckman zeromatic pH meter. Analyses were performed using the procedures and reagents outlined in the HACH instructional manual. When necessary, dilutions of the leachate were prepared, and meter readings multiplied by the dilution factor to obtain the true content. Ferric ion content was obtained by subtracting ferrous ion from total iron content.

A check for viable cells in leachates was performed by inoculating 9K medium (Silverman and Lundgren, 1958) with leachates. A reddish brown deposit on the walls of the test tube was considered positive evidence of growth of the iron oxidizing organisms. No enumerations were run.

Manometric Studies

An adaptation of the HACH BOD apparatus was adopted for this study. Four different energy sources were placed in the BOD bottles which contained 155 ml of sterile 9K mineral salt solution. These subtrates included 4 grams gray Sewickley sandstone (from near Smithtown) with 18% sulfur, impure coal with 4% sulfur, 2 grams of ferrous iron as ferrous sulfate, and 2 grams elemental sulfur. A bottle containing only the salt solution was included as a check. Two series of bottles were used, one was inoculated with 5 ml fresh acid mine drainage (from a deep mine) known to contain the microorganisms in sufficient quantities, and the other received 5 ml of sterile deionized distilled water. Twenty percent KOH solution served as the CO_2 absorbant. After equilibration to 20°C the manometers were sealed. Readings were taken over a period of 48 days.

An identical study is under way, with the exception that a CO_2 buffer (See Pardee method in Umbreit, et al., 1964) has been substituted for the KOH CO_2 absorbent.

Formation of Acid Spots Under Laboratory Conditions

In order to investigate properties of acid spots, pieces of spoil material approximately 1 1/2 inches (3.8 cm) diameter were placed in weathered sandstone mine spoil material (pH 4.7), in greenhouse flats. Spoil materials used were a pyritic shale, metallic pyrite, and high sulfur gray sandstone. Duplicate samples were used, one receiving 200 ml distilled water weekly and the other receiving 400 ml per week. In each end of the flat one piece of spoil material was buried 1/2 inch (1.3 cm) below surface while the other remained on the surface. All samples were seeded with a mixed culture of *Thiobacillus thiooxidans*, *Thiobacillus ferrooxidans* and *Ferrobacillus ferrooxidans*.

Oxidation of Carbonate-Rich vs. Non-Carbonate Pyritic Sandstone

Pairs of sandstone samples of nearly equal sulfur content were selected. One set of samples contained carbonates and the other did not. Samples with carbonates were: A-9, 0.001% S; A-34, 0.275% S; A-35, 0.720% S. Samples without carbonates: H-10, 0.001% S; H-19, 0.285% S; H-35, 0.750% S. Two grams of each spoil sample were placed in 100 ml of sterile 9K mineral salts solution in a 250 ml screw cap Erlenmeyer flask. The flasks were inoculated at room temperature. One set of flasks was withdrawn from the shaker each week and the pH of the solution checked with a Beckman Zeromatic pH meter with a combination glass electrode. Flasks were shaken for as long as five weeks. Several flasks containing elemental sulfur and several containing $FeSO_4 \cdot 7H_2O$ were also tested to verify oxidation.

Results and Discussion

The results of the study to determine the effect of buried depth on the oxidation of pyrite are given in Tables 35, 36, 37, and Figure 24. Except for columns one and two the data are incomplete due to a failure of the apparatus. Spaces in Tables 35 to 37 marked X represent a lack of drainage from that funnel. The funnels either became clogged or the drainage passed by them without collection. A funnel larger than the two inch diameter funnel employed filled with fine sand to provide capillary continuity to the outlet, will be used when the apparatus is reconstructed. Columns one and two best illustrate that oxidation was suppressed when the pyrite was buried 3 inches (7.6 cm) below the surface of the soil column. The total iron measurements (Table 35) indicate that considerably more iron was solubilized at the surface than at the 3 inch depth. It is also apparent from the graphs (Figure 24) that the highest iron contents were reached between the sixth and seventh leachings (12 to 14 weeks). The readings were 7500 ppm total iron and 1000 ppm total iron for columns one and two, respectively. The sulfate contents (Figure 24) of the leachates correspond well with the iron content.

The drainage from the base of the columns in all cases contained little or no iron. Contrary to the characteristic reddish orange color and low pH of the funnel drainage, the drainage from the base was almost colorless and of nearly neutral pH (Table 37). Sulfate content of the base drainage was also reduced but not absent after passing through the remainder of the column.

It is apparent that the iron had precipitated out of solution or replaced exchangeable bases inside the soil column due to the increasing pH or exchangeable bases afforded by the soil used (pH 6.7). Then the sulfate moved downward as a near neutral salt, as evidenced by the relatively high pH values of the leachates.

Iron values were higher in the base leachates where the pyrite was closer to the bottom of the column. The presence of this iron is explainable on the basis that it did not travel as far through the soil column and did not totally precipitate or attach to cation exchange sites in the column. Some iron was also present in the leachate from the control tube, but the quality is insignificant.

The quantities of total iron and sulfate solubilized from the pyrite are sufficient to warrant some special handling in replacement during regrading and reclamation. Since the microorganisms which catalyze the solubilization of the sulfide ores are strict aerobes, it is recom-

Table 35

Total iron content of funnel (F) and bottom (B) leachates (ppm).

	Column No.												
	1		2		3		4		5		6		7
Leaching No.	F	B	F	B	F	B	F	B	F	B	F	B	F
1	80	0	75	0	X	0	Tr	0	45	0	0	0	0
2	85	Tr	0	0	X	0	X	0	0	Tr	X	48	0
3	14	0	0	4	0	0	X	3	X	3	X	3	0
4	325	Tr	138	0	48	0	X	0	X	5	X	0	0
5	800	8	228	3	X	3	X	1	X	5	X	4	4
6	2000	0	1000	0	X	Tr	38	Tr	X	10	X	5	11
7	7500	8	1000	8	X	Tr	3	19	X	20	X	10	16
8	1500	3	550	Tr	X	16	1100	18	1600	33	X	43	0
9	2800	Tr	650	Tr	X	Tr	222	12	360	25	0	30	25
10	330	0	440	25	X	0	460	11	180	25	X	19	18
11	2200	0	475	0	X	0	625	5	350	25	X	16	21
12	1400	0	250	0	X	0	250	4	80	13	X	13	23

Table 36

Sulfate content of funnel (F) and bottom (B) leachates (ppm).

	Column No.												
	1		2		3		4		5		6		7
Leaching No.	F	B	F	B	F	B	F	B	F	B	F	B	F
1	1500	125	1200	75	X	50	1750	50	1725	1300	775	625	100
2	1425	100	1300	250	X	100	X	725	1125	1250	X	3125	60
3	2375	125	1225	425	1025	175	X	825	X	1275	X	1400	Tr
4	1875	500	2000	800	3750	3500	X	200	X	400	X	350	0
5	4250	300	2250	500	X	400	X	725	X	45	X	1500	125
6	8750	325	6250	700	X	3000	0	150	X	750	X	4000	Tr
7	25000	250	2900	375	X	500	375	750	X	825	X	3500	0
8	4500	425	3000	425	X	700	6000	1000	18000	1625	X	4375	Tr
9	10000	700	3500	500	X	650	2100	1125	8500	2250	3900	3750	0
10	7000	750	3000	480	X	525	3400	1175	4200	2275	X	3000	0
11	6500	800	2000	475	X	850	3500	1250	3250	2500	X	2500	0
12	5000	1000	2000	475	X	700	2200	1750	1500	3125	X	2250	0

Table 37

pH of funnel (F) and bottom (B) leachates.

	Column No. 1		2		3		4		5		6		7
Leaching No.	F	B	F	B	F	B	F	B	F	B	F	B	F
1	4.5	6.6	4.9	6.8	X	5.4	5.6	6.0	5.5	4.1	6.0	5.9	6.3
2	2.5	5.9	4.4	6.4	X	6.1	X	6.4	4.3	6.6	X	6.3	6.7
3	3.0	7.0	4.7	6.7	3.6	6.5	X	6.8	X	7.1	X	6.9	8.0
4	2.5	6.5	2.5	6.7	2.8	6.8	X	6.8	X	6.9	X	6.9	6.6
5	2.5	6.4	2.6	6.5	X	6.6	2.8	6.6	X	6.7	X	6.7	6.4
6	2.4	6.8	2.5	7.8	X	8.2	3.6	7.8	X	7.4	X	7.8	8.2
7	2.3	7.3	2.5	7.1	X	7.5	3.5	7.4	X	6.6	X	6.7	7.2
8	2.4	7.0	2.7	7.7	X	8.1	2.4	7.8	2.3	7.9	X	4.1	7.2
9	2.1	7.1	2.2	7.9	X	7.9	2.4	7.6	2.2	7.6	3.4	4.3	7.0
10	2.3	7.3	2.6	7.5	X	7.7	2.4	7.4	2.4	7.3	X	4.0	7.3
11	2.4	7.6	2.5	7.7	X	7.9	2.5	7.6	2.5	7.6	X	4.4	7.5
12	2.2	7.1	2.8	7.2	X	7.3	2.5	7.5	2.5	7.7	X	4.3	7.0

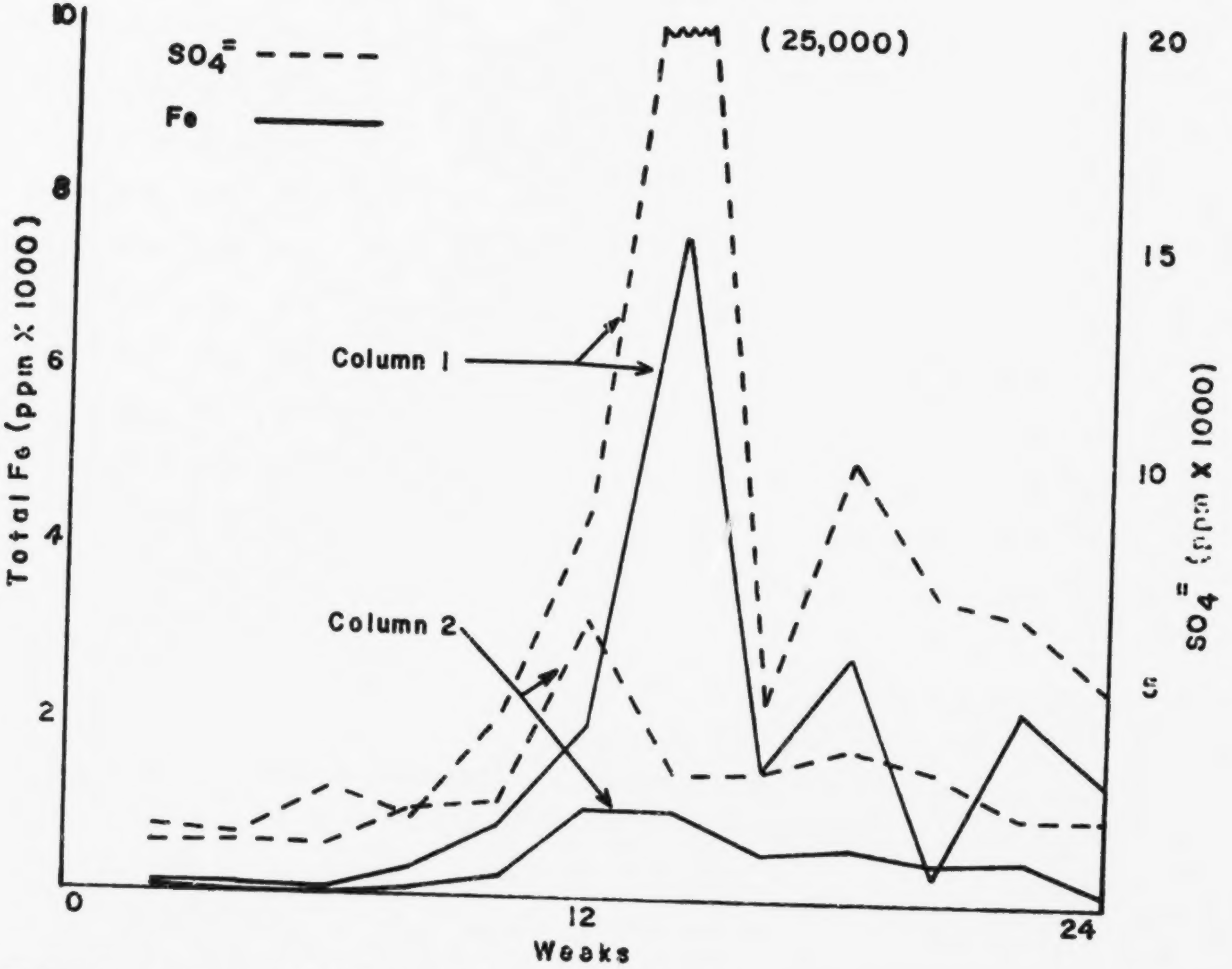

FIGURE 24. IRON AND SULFATE CONTENT OF LEACHATES FROM COLUMNS HAVING PYRITE BURIED AT TWO DEPTHS

mended that highly pyritic spoil materials (pyritic shales, sandstones, etc.) be set aside during removal of overburden and then be buried as deeply as possible where anaerobic (reducing) conditions would most probably exist. This would lead to some abatement of acidic drainage from surface mining operations. Partial evidence for this can be gained from the data of columns one and two.

Other evidence for the microbial activity on spoil materials is illustrated in Figure 25. The graphs represent the oxygen uptake in the presence of various substrates. It is apparent that the biological system exhibits considerably more activity than the sterile system. The pH values of the medium upon termination of the study showed that acid had been produced in the system.

It can be seen from Figure 25 that the biological system exhibits a marked increase in activity over the non-biological system. All curves show an increase in oxygen uptake at approximately 15 days into the study. This is the usual time encountered for the attainment of good cultural activity of the autotrophic iron and sulfur oxidizers.

The marked increase in activity of the system containing coal may be due to the activities of organisms other than the autotrophic population. Reports of heterotrophic growth on coal are not uncommon (Koburger, 1964), and heterotrophic organisms have been isolated from the acid mine drainage used as the inoculum for this study (Millar, 1971).

Acid spots were produced under laboratory conditions on the pyritic shale and metallic-like pyrite. No acid spots formed around the gray sandstone at either moisture level.

The results of the oxidation studies of carbonate vs. non-carbonate spoil material show that acid production did not occur to any great extent in either series of flasks. There was no significant change in pH over a five-week period. The pH increased slightly for some of the carbonate containing A series both inoculated and uninoculated. The failure of the organisms to establish growth and acid production may have been due to the presence of the carbonates. Silverman (1967) reported resistance of a pyrite containing calcium carbonate to bacterial oxidation. This same pyrite when treated with HCl became susceptible to oxidation. These facts point to the possibility that liming a spoil might be beneficial not only through raising the pH toward neutrality but also by introducing a sufficient quantity of calcium carbonate to be inhibitory to the bacterial oxidation of pyritic materials. The maximum pH tolerated by these iron and sulfur oxidizing autotrophs is approximately 5.0.

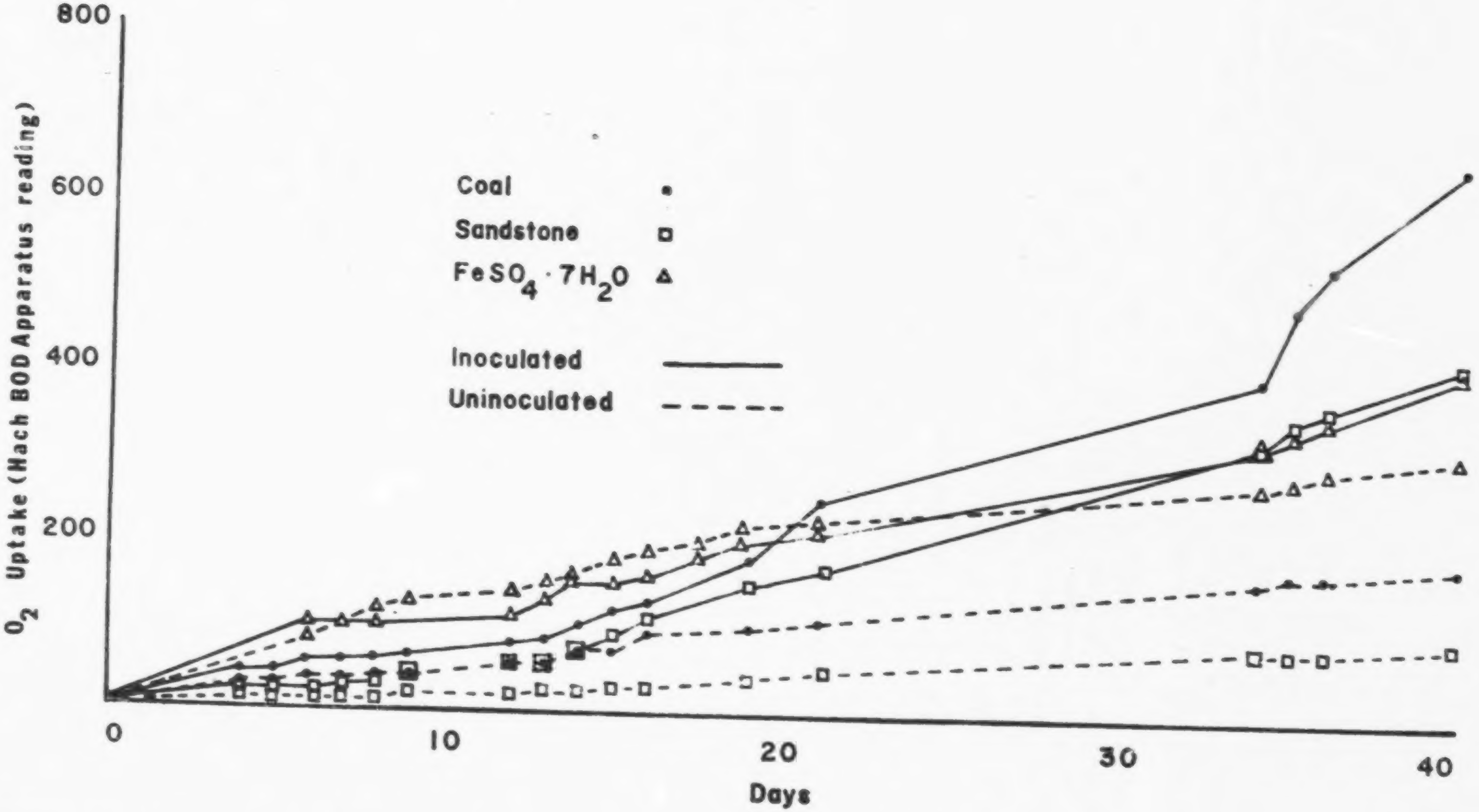

FIGURE 25. OXYGEN UPTAKE OF THREE SUBSTRATES, STERILE, AND INOCULATED WITH ANTOTROPHIC IRON AND SULFUR OXIDIZING MICROORGANISMS

Lack of sufficient growth may also have been due to insufficient quantities of oxidizable substrate. The only sandstone sample to support significant growth was Sewickley overburden containing 18% sulfur, a considerably larger quantity than the .750% sulfur content of H-35, the highest used in the oxidation studies.

Summary

Specially designed miniature lysimeters simulating mine soil land have been tested for rating the activity of chemoautotrophic iron and sulphur oxidizing bacteria on pyrite or rock materials containing variable percentages of pyrite.

Malfunction of some deeply buried interception funnels indicates needed improvements of design, but partial data show that burial of pyrite at a 3 inch (7.6 cm) depth in natural loamy soil of pH 6.7 reduces the rate of release of ferrous iron and sulphate compared to 1/2 inch (1.3 cm) depth of burial. Moreover, percolation downward through the 4 foot (122 cm) column of soil removed most of the acid and iron, presumably by reaction with exchangeable cations in the soils.

There is some evidence, as suggested by others, that alkaline earth carbonates may inhibit bacterial oxidation activity, possibly by preventing pH of 5.0 or less as needed to favor sulphur and iron oxidizing organisms. In some particular rock materials an insufficient quantity of accessible oxidizable substrate may have prevented microbial growth even through appreciable percentages of pyritic sulphur (0.20 to 0.75%) were present.

Slightly modified lysimeters appear promising for calibrating different rock materials and for determining likely effects of burial depth in different kinds of soils or rocks available in problem spoils under natural field conditions.

Manometric methods also allow characterization of relative values of different materials as substrates for chemoautotrophic microorganisms.

SECTION XIII

INTERACTIONS WITH PLANT COVERS

The effectiveness of vegetative cover in reducing water pollution from disturbed land areas has been well documented. Observations made during the course of this project have been primarily related to the thriftiness of plants in local spoil areas composed of specific types of rock materials.

Although there has been little time since the verification of a sulfur-free zone in coal overburden that would allow operators to selectively place this material in positions favorable to establishing vegetation, in several Upper Freeport spoils the sulfur-free rock has "accidentally" been placed on the spoil surface in localized spots. Likewise the acid-producing low chroma massive sandstone occurs in various size fragments on the surface of many spoils.

Overburden materials of some other coal seams, such as the Lower Kittanning and Bakerstown, contain bases, present as carbonates, frequently in sufficient quantity to effectively neutralize acid formed from oxidation of pyritic sulfur, which is present at levels comparable to those in Lower Mahoning sandstone or greater. The higher resulting pH of many of these spoils, along with higher quantities of plant nutrient elements derived from breakdown of shales, and improved water holding capacity obtained in the finer textured weathering products has resulted in highly acceptable revegetation programs on most spoils of these coal seams.

An example of complete failure of revegetation efforts on an older Bakerstown spoil near Albright, Preston County, can be attributed to the inopportune placement of black, highly pyritic shales from just above the coal seam on the spoil surface during the mining operation. The particularly toxic shale in this location attains a thickness of at least 5 meters, and although base status is comparable with overlying strata, the sulfur content is consistently between one and six percent, requiring tremendous quantities of neutralizing material wherever oxidation attacks finely divided forms of the pyrite.

Spoils resulting from surface mining of Lower Kittanning coal in northeastern Preston County have been planted with forage mixtures of birdsfoot trefoil and grasses with great success. The overburden material between the coal seam and the original soil is shale containing, below the weathered zone, the equivalent of 6 tons (average) of calcium carbonate per thousand tons of material. This same material averages

0.236% total sulfur, with the major portion being within 2 meters of the coal seam. Inasmuch as the basic carbonates solubilize rapidly in acid whenever formed from pyrite oxidation, the net pH of the spoil and drainage waters remains near neutrality.

Spoils composed of Lower Mahoning sandstone have been partially covered with thriving stands of birdsfoot trefoil and tall fescue where moderate amounts of lime and fertilizer have also been applied. Localized spoil areas consisting of the weathered (high chroma) sandstone, which has been shown to be free of pyrite, can be depended upon to serve as an acceptable growing medium if the plant nutrients removed during the weathering processes over geologic time are replaced, and some lime is applied to counteract the natural acidity the leaching processes have produced. Areas of spoil dominated by the low chroma, pyritic sandstone are found to be barren of vegetative cover except where extremely heavy rates of lime have been applied. Most of the spoils resulting from mining the Upper Freeport seam consist of a mixture of high chroma, weathered sandstone and low chroma, pyritic sandstone. Where adequate lime and fertilizer have been applied, and seeding time was at the optimum part of the growing season, excellent ground cover has been obtained with the grass/legume mixtures commonly used. Areas containing a large percentage of coarse rock fragments (nearly always of low chroma, and pyritic) and devoid of finer particles could be expected to remain barren.

Observation of several Upper Freeport spoils and a few formerly highly acidic Pittsburgh spoils suggests that rapid establishment of vegetative cover of any type tends to reduce the rate of generation of acid in the spoil. This would be expected, theoretically, because of increased carbon dioxide and reduced oxygen concentrations associated with respiring roots or decomposing organic matter.

Although with proper practices, forage grasses and legumes, seeded alone or in combination with trees, are providing quick cover needed to control erosion and sedimentation on many spoils, it is apparent in this region that native trees will soon convert most mine spoil lands to woodland unless tree seedlings are controlled. In this connection, it appears that some landowners who prefer forages rather than woodland on gentle slopes have failed to realize that vigorous forage stands and growth require repeated applications of lime and fertilizers as well as proper grazing and clipping management. Moreover, wise use of mine spoil land is to be expected only when capabilities of particular spoils are well understood, the same as with other soils.

SECTION XIV

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SECTION XVII

GLOSSARY

Alfisols - Mineral soils that have a light colored surface horizon generally low in organic matter and an argillic (clay accumulation) subsurface horizon which is at least 35 percent base saturated.

Bone coal - Argillaceous coal; or carbonaceous shale in coal seams.

Chroma, color - The relative purity, strength, or saturation of a color; directly related to the dominance of the determining wave length of the light and inversely related to grayness.

Clastics - Any of a group of rocks composed mainly of fragemnts derived from pre-existing rocks and transported mechanically to its place of deposition, such as shales, siltstones, sandstones, and conglomerates.

Control section - Arbitrary depths of soil material within which certain diagnostic horizons, features, and other characteristics are used as differentiae in the classification of soils.

Cubic Udspolents - Thick-bedded Spolents of a humid climate (tentatively defined).

Diagenesis - The reconstruction processes, collectively, operating in sedimentary rocks during or immediately after their deposition to produce changes in them, and caused by the weight of the overlying strata, hot waters, etc.

Dystrochrepts - Inceptisols having a light colored surface horizon and low base saturation.

Entisols - Soils that have little or no evidence of development of pedogenic horizons.

Facies - An assemblage of mineral, rock, or fossil features reflecting the environment in which a rock was formed.

Fissile Udspolents - Shaley Spolents of a humid climate (tentatively defined).

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Fragiudalfs - Alfisols of a humid climate having a brittle, loamy subsurface pan.

Free Al - Aluminum extractable by the dithionite-citrate method as described by Jackson (1958).

Free Fe - Iron extractable by the dithionite-citrate method as described by Jackson (1958).

Free Mn - extractable by the dithionite-citrate method as described by Jackson (1958).

Hapludalfs - Alfisols of a humid climate that have simple or minimum horizonation.

Hapludults - Ultisols of a humid climate that have simple or minimum horizonation.

Hue, color - The dominant spectral color, related to the dominant wavelength of light.

Inceptisols - Soils with one or more diagnostic horizons that do not represent significant illuviation or eluviation of clays.

Kaolinite books - Fine mosaiclike masses of crystals apparently replacing feldspars.

Pedogenic - Having to do with the formation of soil.

Penecontemporaneous - Living, existing or occurring at nearly the same time.

Plattic Udspolents - Sandstone Spolents of a humid climate (tentatively defined).

Slickensides - Polished and grooved surfaces produced by one mass sliding past another.

Spolents - An Entisol soil composed of spoil material (tentatively defined).

Surface Mining - Removal of mineral or other resources from the earth by first removing overlying soil and rock materials; in this report auger mining is not included.

Typic Udspolents - Humid climate Spolents of mixed sandstones and shales (tentatively defined).

Ultisols - Soils of humid areas characterized by the presence of an argillic subsoil horizon which is less than 35 percent saturated with bases.

Value, color - The relative lightness or intensity of color and approximately a function of the square root of the total amount of light.

SECTION XVIII

APPENDIX A

Preston County Sites Where Rock Chip, High Wall, Spoil and Soil Samples Have Been Obtained and/or Studied in Place

A - One mile south and one-half mine west of Valley Point; Upper Freeport coal; drainage into lower Glade Run, active 1969-1971.

B - One and one quarter miles west of Valley Point; Upper Freeport coal; drainage into upper second west fork of Glade Run; graded and planted to locust and autumn olive in 1969.

C - Three-fourth mile south and one mile west of Valley Point; Upper Freeport coal; drainage into west fork of Glade Run; active 1969-1971.

D - One-half mile south of Valley Point; Upper Freeport coal; drainage into Fickey Run; spoil graded and unplanted.

E - Two and one-half miles south and one and one quarter miles east of Brandonville; Upper Freeport coal; drainage into lower first order tributary of Little Sandy Creek; active 1969-1971.

F - One and one-half mile south and one quarter mile west of Lenox; Upper Freeport coal; drainage into Little Lick Run; active 1969-1970, spoil partially graded and planted 1970-1971.

G - One and one quarter miles south and one and one-half miles west of Valley Point; Upper Freeport coal; drainage into Glade Run; active 1969-1971.

H - Two and one quarter miles west of Valley Point; Upper Freeport coal; drainage into Sovern Run; active 1969-1970, grading started 1971.

I - One-half mile toward Lenox from site F; Upper Freeport coal; drainage into Little Lick Run; active 1969-1970, grading started 1971.

J - One and one-half miles west of Manown; Upper Freeport coal; drainage into north fork of Squires Creek; active 1969-1970, grading started 1971.

K - One quarter mile toward Lenox from site F; Upper Freeport coal; drainage into Little Lick Run; active 1969-1970, grading started 1971.

L - One-half mile south and one-half mile west of Valley Point; Upper Freeport coal; drainage into Glade Run; active 1969-1970, graded and planted to forage mixture 1971.

M - Three quarter mile south and one-half mile west of Herring; Upper Freeport coal; drainage into Bull Run; active 1969-1971, partially graded and planted to locust trees prior to 1969.

N - Two miles east and two and one-half miles north of Brandonville; Upper Freeport coal; drainage into tributary of Big Sandy Creek; active 1970, grading started 1971.

O - Two and one-half miles east and two miles north of Brandonville; Lower Kittanning coal; drainage into Glade Run, a first order tributary of Big Sandy Creek; active 1969-1971, partially graded and planted to forage species.

P - One mile east and one mile south of Caddell; Lower Kittanning coal; drainage into Buffalo Run; graded and planted 1970.

Q - One mile south and one quarter mile east of Valley Point; Bakerstown coal; drainage partly into Fickey Run and partly into Muddy Creek; graded and revegetated to forage mixture 1969.

R - One quarter mile north and one quarter mile east of Lenox; Bakerstown coal; drainage into tributary of Muddy Creek; active 1969-1970, graded 1971.

S - One mile south and one-half mile west of Lenox; Bakerstown coal; drainage partly into Crab Orchard Run and partly into Little Lick Run; active 1971.

T - One-half mile north and one and one-half miles east of Albright; Bakerstown coal; drainage into Roaring Creek; active 1971.

U - One and one quarter miles south and two miles west of Howesville; Bakerstown coal; drainage into tributary of Birds Creek; active 1970, graded 1971.

V - One and one quarter miles south and one-half mile east of Caddell; Bakerstown coal; drainage into Buffalo Run; graded and planted to forage species 1970.

W - Three quarter mile south and one quarter mile west of Lenox; Harlem coal; drainage into Crab Orchard Run; active 1970-1971.

X - Three quarter mile south and three quarter mile east of Valley Point; Harlem coal; drainage partly into Fickey Run and partly into Muddy Creek; graded and revegetated to forage mixture 1969.

Y - One and one quarter miles south and three quarter mile west of Glade Farms; Brush Creek coal; drainage into Hog Run; active 1970-1971, partly graded 1971.

Z - Three-fourth mile south and one-half mile east of Caddell; Mahoning coal; drainage into Buffalo Run; graded and revegetated to forage mixture 1970.

APPENDIX B

Soil Profile Descriptions

Site A

DATE: September 30, 1969

LOCATION: On strip mine south of Valley Point

SAMPLED AND DESCRIBED BY: Taylor, Gorman, Smith

SLOPE: 3 to 8 percent

Horizons:

Ap	0-6" (0-15 cm)	--Dark grayish brown (19YR 4/2) loam; weak, fine, granular structure; very friable; 5 percent sandstone fragments; common roots; clear, wavy boundry.
A3	6-10" (15-25 cm)	--Dark yellowish brown (10YR 4/4) fine sandy loam; weak, fine granular structure; very friable; 5 percent sandstone fragments; common roots; clear, wavy boundry.
B2	10-18" (25-46 cm)	--Yellowish brown (10YR 5/6) light sandy clay loam; weak, fine to medium, subangular blocky structure; friable to firm; 15 percent sandstone fragments; few roots; clear, wavy boundary.
C	18-22" (46-66 cm)	--Thin platy sandstone with 5 percent sandy loam inclusions in cracks and between thin strata; massive soil structure; gradual, wavy boundary.
R	22" + (66 cm+)	--Sandstone.

Series: Dekalb, thin variant

Great Group: Dystrochrepts

APPENDIX B

Soil Profile Description

Site C

DATE: September 30, 1969

LOCATION: West of Valley Point, above active Strip Mine

SAMPLED AND DESCRIBED BY: Taylor, Gorman, Smith

SLOPE: 3 to 8 percent

Horizons:

Ap1	0-2" (0-5 cm)	--Very dark grayish brown (10YR 3/2) loam; weak, fine, granular structure; very friable; 5 percent sandstone fragments; many roots; clear, wavy boundary.
Ap2	2-10" (5-25 cm)	--Dark grayish brown (10YR 4/2) loam; weak, fine, granular structure; firm in place; very friable when broken out; 5 percent sandstone fragments; common roots; clear, wavy boundary.
B2	10-18" (25-46 cm)	--Yellowish brown (10YR 5/6) channery loam; weak, fine to medium, subangular blocky structure; friable; 25 percent sandstone fragments; few roots; clear, irregular boundary.
B3	18-21" (46-53 cm)	--Yellowish brown (10YR 5/6) very channery loam; weak, fine subangular blocky structure; friable; 60 percent sandstone fragments; occasional roots; gradual, wavy boundary.
C	21-24" (53-61 cm)	--Yellowish brown (10YR 5/6) fine sandy loam; massive structure; 10 percent fines similar to those in B3 horizon; gradual, wavy boundary.

Appendix B
Site C - Continued

Horizons:

R 24" + (61 cm+) --Sandstone.

Series: Dekalb

Great Group: Dystrochrepts

APPENDIX B

Soil Profile Description

Site E-1

DATE: October 17, 1969

LOCATION: Appalachian Coal, stripping operation, approximately 3 miles north of Centenary church and one mile east of the Brandonville to Terra Alta Pike. Preston County, W. Va.

SAMPLED AND DESCRIBED BY: Singh, Christiansen, Grube, Jencks and Smith

SLOPE: 2 percent

VEGETATION: Mixed legume (Birdsfoot trefoil) and grass meadow.

Horizons:

Ap	0-8" (0-20 cm)	--Dark brown (10YR 3/3) silt loam; moderate, medium and fine, granular structure, friable moist; somewhat irregular fingering into B1; common roots; clear boundary.
B1	8-12" (20-30 cm)	--Yellowish brown (10YR 5/6) silty clay loam; weak, medium, subangular blocky and granular structure; common roots; gradual boundary.
B2t	12-19" (30-48 cm)	--Brownish yellow (10YR 6/6) silty clay loam; moderate, medium, subangular blocky structure; friable moist; discontinuous clay skins; common roots; clear, smooth boundary.
Bx1	19-22" (56-69 cm)	--Brownish yellow (10YR 6/6 to 6/8) silty clay loam; common, distinct brownish yellow (10YR 6/6) and light gray (10YR 6/2 mottles; weak, medium, subangular blocky structure with massive ped interiors; firm moist; fine concretions; few roots; gradual, irregular boundary.

Appendix B

Site E-1 - Continued

Horizons:

Bx2	22-27" (56-69 cm)	--Yellowish brown (10YR 5/6 to 5/8) silty clay loam; common, distinct yellowish brown (10YR 5/6), light gray (10YR 7/2) and black (10YR 2/1) mottles; weak platy and subangular blocky structure with massive ped interiors; firm moist; fine brown and discontinuous black concretions and/or concretions of black coatings; few roots; abrupt boundary.
R	27" + (69 cm+)	--Gray and brown sandstone with dark brown or black coatings on some bedding surfaces and fractures; firm; bedding 2 to 4 inches thick; variable depth.
IIBx	40-46" (102-117 cm)	--(This horizon was described 15 feet north of the previously described pedon.) Brownish yellow (10YR 6/6) silty clay loam; common, prominent light gray (10YR 7/2) mottling; coarse blocky or prismatic structure cutting across weak platy atructure or horizontal planes (possibly inherited in part from siltstone or shale bedding); firm moist; light gray color appeared to be a coating of thickness 0 to 10 mm on the exterior of coarse blocky, prismatic and platy peds; coating appeared too porous to be clay skins.

Series: Cookport, fine silty variant.

Great Group: Fragiudults

APPENDIX B

Soil Profile Description

Site E-2

DATE: April 16, 1970

LOCATION: Above mouth of Beaver Creek into Little Sandy Creek, Preston County. Level upland within Upper Freeport outcrop.

SAMPLED AND DESCRIBED BY: Arnold, Grube, Smith

SLOPE: 1 to 2 percent

VEGETATION: Meadow of orchardgrass, red clover and birdsfoot trefoil.

Horizons:

Ap	0-7" (0-18 cm)	--Brown (10YR 3.5/3) silt loam; moderate, fine granular structure; friable; many fibrous roots; abrupt, wavy boundary.
B1	7-16" (18-41 cm)	--Yellowish brown (10YR 5/6) silty clay loam; moderate, medium, subangular blocky structure; friable; 5 percent inclusions of earthworn casts or rodent diggings of Ap horizon; air dry color is very pale brown (10YR 7/4) with concretionary material and traces of mottling and 5 percent small stone fragments +2 mm; common roots; clear to gradual boundary.
B21t	16-20" (41-51 cm)	--Yellowish brown (10YR 5/6) silty clay loam; very pale brown (10YR 7/3) and white (10YR 8/2) mottles especially at boundary with the B23t horizon; moderate, medium, subangular blocky structure; circular channels, probably crayfish burrows, partly filled with Ap soil, penetrate the horizon carrying water which seeped into the soil plot; common roots; clear boundary.

Appendix B
Site E-2 - Continued

Horizons:

B22t	20-23" (51-58 cm)	--Yellowish brown (10YR 5/6) silty clay; many prominent light gray (10YR 7/2) mottles; yellowish red (5YR 4/8) and dark reddish brown (5YR 2/2) iron and manganese concretionary material cementing part of this horizon and underlying horizon in vertical or oblique zones; few roots.
B3t	23-39" (58-99 cm)	--Strong brown (7.5YR 5/6) silty clay; many prominent white (10YR 8/2) to black (10YR 2/1) mottles; black (10YR 2/1) and dark reddish brown (5YR 2/2) iron and manganese concretionary bands and coatings; moderate, medium, subangular blocky to angular blocky structure; friable to firm moist; many white (10YR 8/2) clay skins; very few roots.
R	39-42" (99-107 cm)	--Pale brown (10YR 6/3) siltstone bedded 1/2 to 1 inch thick; somewhat mottled with yellowish brown (10YR 5/6) to white (10YR 8/1) on cleavage planes and some fractures coated with black (10YR 2/1) and dark reddish brown (5YR 2/2).

Series: Wharton

Great Group: Hapludults

APPENDIX B

Soil Profile Description

Site E-3

DATE: April 18, 1970

LOCATION: Near the top of the ridge approaching the southeast fence corner and gate at UFE. See UFE II and I for other details of locations.

DESCRIBED AND SAMPLED BY: Grube and Smith

VEGETATION: Like UFE II

SLOPE: Like UFE II

Horizons:

Ap	0-9" (0-23 cm)	--Like UFE II; not sampled.
B1	9-14" (23-36 cm)	--Yellowish brown (10YR 5/4) heavy silt loam; moderate, medium, subangular blocky structure; 10 percent siltstone fragments; inclusions of Ap in earthworm casts; common roots.
B21t	14-24" (36-61 cm)	--Brownish yellow (10YR 6/6) silty clay loam; few, faint light gray (10YR 7/2) to black (10YR 2/1) mottles; 10 percent reddish brown (2.5YR 4/4) coarse shale fragments +2 mm and -20 mm.
B22t	24-28" (61-71 cm)	--Yellowish brown (10YR 5/6) silty clay; common light gray (10YR 6.5/1) to reddish brown (2.5YR 4/4) mottles; weak, angular blocky structure; 10 percent shale or siltstone fragments +2 mm; common clay skins.

Appendix B

Site E-3 - Continued

Horizons:

Bm	28-30" (71-76 cm)	--Cemented, indurated continuous pan of empty iron-manganese concretionary material dominantly reddish brown (5YR 2/2) shading to black and to layers of brownish yellow (10YR 6/6); some concretion interiors are empty, others contain small silty mud balls of pinkish gray (7.5YR 6/2); grayish brown (10YR 5/2), and light brownish gray (10YR 6/2) that look much like earthworm casts.
B3	30-32" (76-81 cm)	--Yellowish brown (10YR 5/6) silty clay loam to silty clay; light gray (10YR 6/1 to 7/1) mottles; massive structure; some siltstone controlled layering.
R	32-33"+ (71-84+ cm)	--Siltsone; mottles on broken faces of light gray (10YR 6/1), strong brown (7.5YR 5/8), reddish brown (5YR 4/4) and minor black (7.5 YR 2/0) coatings; firm.

Series: Wharton

Great Group: Hapludults

APPENDIX B

Soil Profile Description

Site F

DATE: February 5, 1970

LOCATION: 1/2 mile south of Lennox, Kingwood Mining, active site, job 3.

SAMPLED AND DESCRIBED BY: Grube, Alt, Smith

SLOPE: 2 percent

VEGETATION: Orchardgrass and miscellaneous forbs. Possibly an old orchard.

Horizons:

Ap	0-10" (0-25 cm)	--Dark grayish brown (10YR 4/2) silt loam with 10 percent inclusion of pale brown (10YR 6/3) heavy silt loam; medium granular structure; friable moist; very few small shale (siltstone) particles +2 mm diameter; noticeable earthworm casts and canals; common roots; abrupt boundary.
B2	10-17" (25-43 cm)	--Yellowish brown (10YR 5.5/6) silty clay loam; moderate, medium, subangular blocky structure with slightly lighter color value on ped faces; friable moist; 5 percent inclusions of A horizon grayish brown (10YR 5/2) silt loam; few clay skins; grass roots and earthworms present; clear boundary.
B3	17-22" (43-56 cm)	--Brownish yellow (10YR 6/6) shaly silty clay loam; weak, medium to fine, subangular blocky structure with slightly lighter color values on ped faces; friable moist; 35 percent silty shale fragments mottled with colors from white (10YR 8/2) to dark yellowish brown (10YR 4/4); few grass roots.

Appendix B

Site F - Continued

Horizons:

C	22-26" (56-66 cm)	--Brownish yellow (10YR 6/6) very shaly silt loam; massive soil structure; 50 percent siltstone mottled light brownish gray (2.5YR 6/2) to pale yellow (2.5YR 7/4) to black (N 2/0) on cleavage planes.
R	26-30" (66-76 cm)	--Siltstone, mottled light brownish gray (2.5YR 6/2), pale yellow (2.5YR 7/4) and black (N 2/0) on cleavage planes, with 5 to 10 percent massive silt loam fines between bedding planes.

Series: Gilpin

Great Group: Hapludults

APPENDIX B

Soil Profile Description

Site H

DATE: October 23, 1969

LOCATION: Preston County - Rockville operation - Kingwood Coal
Permit No. 9369.

SAMPLED AND DESCRIBED BY: Smith, Sponaugle, Taylor, Gorman

SLOPE: 3 to 8 percent

VEGETATION: Old field.

Horizons:

Ap1	0-2" (0-5 cm)	--Very dark grayish brown (10YR 3/2) loam; moderate, fine, granular structure; very friable; 5 percent sandstone fragments; clear, wavy boundary.
Ap2	2-7" (5-18 cm)	--Dark brown (10YR 4/3) loam; moderate, fine, granular structure; very friable; 5 percent sandstone fragments; clear, wavy boundary.
B21	7-13" (18-33 cm)	--Yellowish brown (10YR 5/4) loam; weak, fine subangular blocky structure; friable; 15 percent sandstone fragments; clear, irregular boundary.
B22	13-21" (33-53 cm)	--Yellowish brown (10YR 5/6) channery loam; weak, fine and medium, subangular blocky structure; 40 percent sandstone fragments; gradual irregular boundary.
C	21-27" (53-69 cm)	--10 percent yellowish brown (10YR 5/6) loam to fine sandy loam; massive; friable to firm; 90 percent thin bedded sandstone; gradual, irregular boundary.

Appendix B

Site H - Continued

Horizons:

R 27" + (69 cm+) --Hard, somewhat broken sandstone.

Series: Dekalb

Great Group: Dystrochrepts

APPENDIX B

Soil Profile Description

Site I

DATE: February 24, 1970

LOCATION: Freeport coal operation on Alexander's permit, 1/2 mile south of Lennox. Drainage into Little Lick Run.

SAMPLED AND DESCRIBED BY: Grube and Smith

SLOPE: 5 percent, on upland bench

VEGETATION: Short grass, closely utilized, dominantly orchardgrass.

Horizons:

Ap	0-7" (0-18 cm)	--Dark brown (10YR 3/3) silt loam or very fine sandy loam; moderate, medium to fine, granular structure; friable moist; irregular fingering into B1; 5 to 10 percent coarse fragments of fine-grained sandstone smaller than 3 inches diameter; common roots; abrupt boundary.
B1	7-12" (18-30 cm)	--Yellowish brown (10YR 5/6) channery loam or channery very fine sandy loam; weak, medium, subangular blocky to granular structure; friable moist, 10 percent surface soil inclusions; 20 percent coarse fragments of bedded fine grained sandstone; common roots; gradual boundary.
B2	12-20" (30-51 cm)	--Yellowish brown (10YR 5/6 to 5/8) loam or very fine sandy clay loam; weak, medium, subangular blocky structure; friable moist; fine roots; gradual boundary.

Appendix B
Site I - Continued

Horizons:

B3	20-30" (51-76 cm)	--Yellowish brown (10YR 5/6 to 5/8) very channery loam to very channery very fine sandy loam marginal to very channery clay loam; weak, medium, subangular blocky structure; friable moist; 50 percent coarse fragments less than 3 inches diameter with bedding planes partially coated with black and rock interiors as well as some fines mottled with very pale brown (10YR 7/3 to 7/4); very few, fine roots.
C	30-36" (76-91 cm)	--Yellowish brown (10YR 5/8) to reddish yellow (7.5YR 6/6) very channery fine sandy clay loam; common, distinct mottles of very pale brown (19YR 7/3 to 8/3); 75 percent fine-grained thin bedded sandstone fragments; discontinuous clay films; very few, very fine roots.
R1	42-48" (1.07-1.22 m)	--Fine grained, thin bedded sandstone with 10 percent fine sandy loam or fine sandy clay loam fines between peds; bedding planes partially coated with black; rock interior and fines mottled yellowish brown (10YR 5/8), reddish yellow (7.5YR 6/6), yellowish red (5YR 5/6) and weak red (2.5YR 5/2) to reddish brown (2.5YR 5/4).
R2	53-58" (1.36-1.47 m)	--Fine grained, moderately thin bedded sandstone with 5 to 10 percent fine sandy clay loam fines between bedding planes; dominant color reddish brown (5YR 5/3) with mottles from white (5YR 8/1) to black.
R3	70-75" (1.78-1.91 m)	--Fine grained sandstone like R2 but tending toward thicker beds, less fines, and bigger slabs between fractures.

Series: Dekalb

Great Groups: Dystrochrepts

APPENDIX B

Soil Profile Description

Site J

DATE: April 14, 1970

LOCATION: 1/2 mile west of Mt. Phoebe, Preston County on Upper Freeport operation of Mary Ruth Coal Company.

SAMPLED AND DESCRIBED BY: Grube and Smith

VEGETATION: Woodland with small trees and shrubs remaining. Moss, rhododendron, oaks, sassafras.

Horizons:

01 and 02	5"-0 (13 cm-0)	--Undifferentiated, loose, undecomposed leaves and decomposed organic matter held together by abundant fine roots; mineral fraction dominantly sand; clear boundary.
A2	0-1" (0-3 cm)	--White (N 9/0) medium to coarse sand mixed with decomposed organic matter and including 10 percent of brown (10YR 5/3) loamy material; dominantly structureless, single-grained; 5 percent sandstone fragments +2 mm.
A3	1-5" (3-13 cm)	--Brown (10YR 4/3) loam containing very little silt; moderate, fine, granular structure; very friable; 10 percent sandstone fragments +2 mm; 5 percent dark granules of high organic materia; common roots.
B21	5-12" (13-30 cm)	--Yellowish brown (10YR 5/5) channery heavy loam; moderate, medium to fine, granular structure; very friable; 25 percent sandstone fragments +2 mm; sandstone fragments mottled very light gray (10YR 4/4) or broken faces; common roots.

Appendix B
Site J - Continued

Horizons:

B22 12-20" (30-51 cm) --Yellowish brown (10YR 5/6) very channery heavy loam to clay loam; moderate, medium, granular to subangular blocky structure; friable; 50 percent medium textured sandstone fragments of mottled light gray (10YR 7/1) to dark yellowish brown (10YR 4/4); common roots.

R 20-25" (51-64 cm) --Medium textured sandstone with 10 percent fines between bedding planes; freshly broken faces dominantly brownish yellow (10YR 6/6) but grading from light gray (10YR 7/2) to olive yellow (5YR 6/6).

Series: Dekalb

Great Group: Dystrochrepts

APPENDIX B

Soil Profile Description

Site K

DATE: April 9, 1970

LOCATION: Kingwood Mining operations, probable northern extension of UFF (Job 3) or southern extension of UFI (Alexanders).

SAMPLED AND DESCRIBED BY: Singh, Grube, Smith, Veatch

VEGETATION: Short grass (redtop), weeds (cinquefoil), moss, scattered hawthorn and other small trees. Old scattered nearby trees are oaks and maples. Possibly an old orchard.

Horizons:

02	2"-0 (5 cm-0)	--Very dark brown (10YR 2/2) loam; moderate, fine granular structure; friable, held firmly by fibrous roots; few sandstone fragments +2 mm diameter; clear boundary.
A1	2-8" (5-20 cm)	--Brown to dark brown (10YR 3.5/3) loam; moderate, fine granular structure; friable to loose; 10 percent sandstone fragments up to 3 inches diameter; 5 percent inclusion of pale brown material apparently originally earthworm casts or rodent diggings; common fibrous roots.
B21	8-18" (20-46 cm)	--Yellowish brown (10YR 5/6) channery loam marginal to channery clay loam; moderate, fine granular structure; friable; 5 to 10 percent inclusions of brown or dark brown material, apparently earthworm casts and rodent diggings; 20 percent sandstone fragments to 4 inches diameter; noticeable quantities of medium or coarse sand with apparently very little silt; common fibrous roots and a few coarse (woody) tree roots; gradual boundary.

Appendix B
Site K - Continued

Horizons:

B22	19-30" (46-76 cm)	--Brownish yellow (5.5/6) channery loam containing more coarse sand than the B21; moderate to weak, fine granular structure; friable; 25 percent brown mottled, medium to coarse grained sandstone with partial coatings of dark brown to black; fibrous and woody roots but fewer than B21; abrupt boundary but depth somewhat variable.
R	30-36" (76-91 cm)	--Medium to coarse sandstone with 5 percent sandy loam between bedding planes; mottles of very pale brown (10YR 8/3) to yellowish brown (10YR 5/8) with significant black coatings on bedding planes and on some grains.

Series: Dekalb

Great Group: Dystrochrepts

APPENDIX B

Soil Profile Description

Site L

DATE: May 14, 1970

LOCATION: Preston County, west of Valley Point.

SAMPLED AND DESCRIBED BY: Pyle, Grube and Smith

SLOPE: 2 percent

VEGETATION: Maples, fire cherry, blueberry, teaberry, and greenbrier.

Horizons:

A1	0-7" (0-18 cm)	--Very dark grayish brown (10YR 3/2) to dark brown (10YR 3/3) loam; moderate to strong, fine, granular (or crumb) structure with some platelike structures; very friable; 5 percent channery sandstone fragments smaller than 2 inches wide; many roots; clear boundary.
A3	7-12" (18-30 cm)	--Dark yellowish brown (10YR 4/4) loam; moderate, fine to medium, granular structure; very friable; less than 5 percent channery sandstone fragments 1 to 5 inches in length; common fine roots; clear boundary.
B2	12-19" (30-48 cm)	--Yellowish brown (10YR 5/6 to 5/8) clay loam marginal to loam; faint mottling in lower two inches; moderate, medium, granular structure with some subangular blocky structure; friable; 5 to 7 percent coarse channery sandstone fragments to 2 1/2 inches; few roots; clear boundary.

Appendix B

Site L - Continued

Horizons:

Bx1	19-26" (48-66 cm)	--Yellowish brown (10YR 5/8) clay loam; common mottles of light gray (10YR 7/1) and black (10YR 2/1); firm; mottling and brittleness indicative of fragipan but less distinct than for underlying horizon; 15 percent channery sandstone fragments to 4 inches; clear boundary.
Bx2	26-42" (66-170 cm)	--Yellowish brown (10YR 5/6 to 5/8) to light yellowish brown (10YR 6/4) and brownish yellow (10YR 6/6) clay loam; many continuous light gray (10YR 7/1) streaks and common black (10YR 2/1) and dark brown (10YR 3/3) mottles; firm and brittle; some of the gray streaks are traceable bounding surfaces of large prisms, the tops and bottoms of which are not clearly defined; many vesicular openings some of which have dark brown to black coatings and a reticulate pattern, apparently partially filling old root channels; 15 percent channery fragments finer than 4 inches.
Cx and 5	42-52" (107-132 cm)	--Yellowish brown (10YR 5/6) and dark brown (10YR 3/3) very channery clay loam to very channery sandy loam; prominent light gray (10YR 7/1) and common black (10YR 2/1) mottles; variable proportions of fines and weathered bedded sandstone between 50 percent and 95 percent; very slowly permeable.

Series: Cookport

Great Group: Fragiudults

APPENDIX B

Soil Profile Description

Site, test core FP25

DATE: October 23, 1969

LOCATION: Preston County, Northwest of Cuzzart on rounded hill (elevation 2208 ft.) above surface mining operations. Profile is near site of core borings FP25 and 25a.

SAMPLED AND DESCRIBED BY: Smith, Sponaugle, Taylor, Gorman

VEGETATION: Brushy old field.

Horizons:

Ap1	0-2" (0-5 cm)	--Very dark grayish brown (10YR 3/2) channery coarse silt loam; weak, fine, granular structure; very friable; 20 percent rock fragments; clear, wavy boundary.
Ap2	2-8" (5-20 cm)	--Dark brown (10YR 3/3) channery loam; weak, fine to medium, granular structure; very friable; 20 percent rock fragments; clear, wavy boundary.
B2	8-16" (20-41 cm)	--Yellowish brown (10YR 5/6) very channery loam; weak, fine to medium, subangular blocky structure; friable; 50 percent rock fragments; gradual, irregular boundary.
C	16-27" (41-69 cm)	--Thin bedded sandstone (1 to 3 inches thick) interbedded with soft, weathered, yellowish brown siltstone; few mica flakes, variable 10 to 15 percent yellowish brown (10YR 5/6) loam in crevices and pockets.

Series: Dekalb, thin variant

Great Group: Dystrochrepts

APPENDIX C

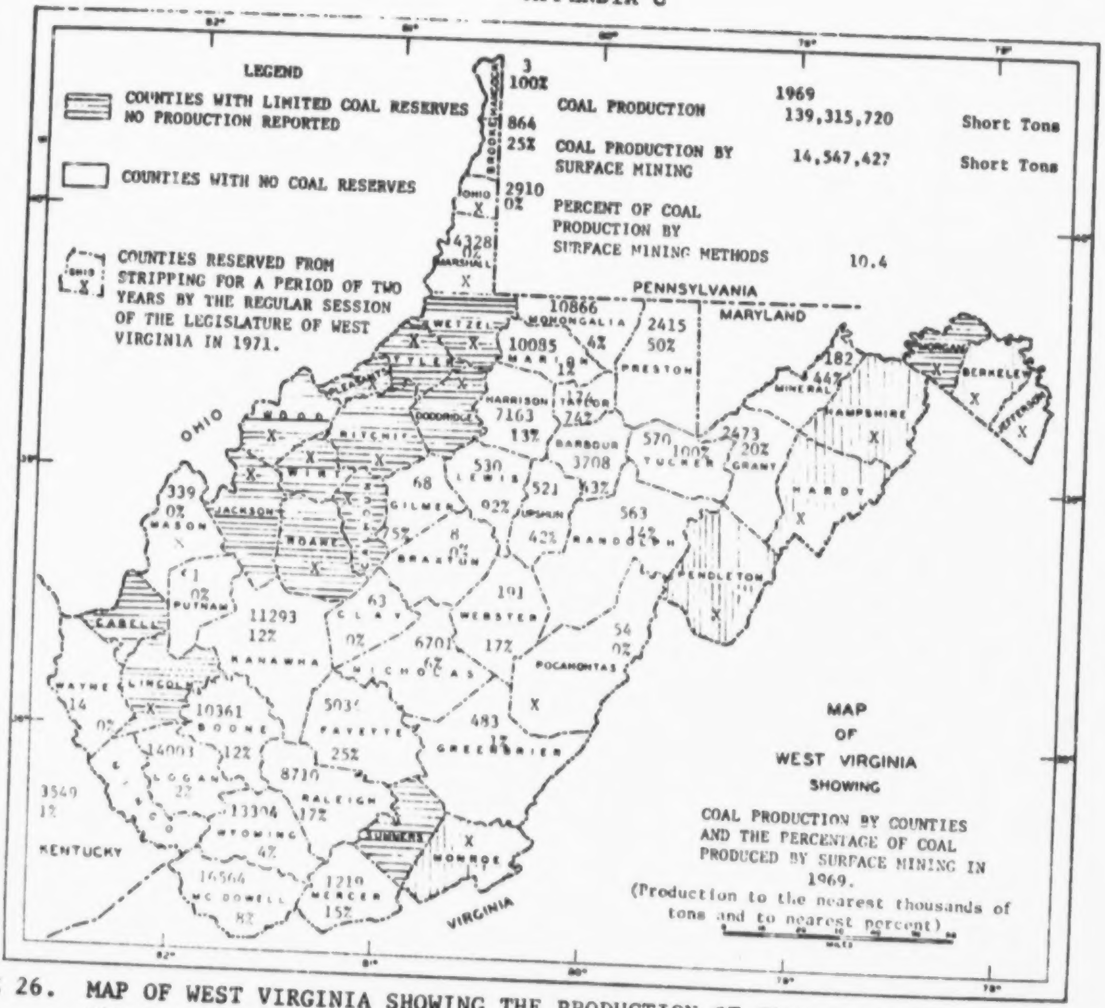
LEGEND
COUNTIES WITH LIMITED COAL RESERVES NO PRODUCTION REPORTED
COUNTIES WITH NO COAL RESERVES
COUNTIES RESERVED FROM STRIPPING FOR A PERIOD OF TWO YEARS BY THE REGULAR SESSION OF THE LEGISLATURE OF WEST VIRGINIA IN 1971.
OHIO
1969
COAL PRODUCTION 139,315,720 Short Tons
COAL PRODUCTION BY SURFACE MINING 14,547,427 Short Tons
PERCENT OF COAL PRODUCTION BY SURFACE MINING METHODS 10.4
PENNSYLVANIA
MARYLAND
KENTUCKY
VIRGINIA
OHIO
HANCOCK 3 100%
BROOKE 864 25%
OHIO 2910 0% X
MARSHALL 4328 0% X
WETZEL X
TYLER X
PLEASANTS X
DODDRIDGE X
WOOD X
RITCHIE X
WIRT X
JACKSON X
ROANE X
CALHOUN X
MONONGALIA 10866 4%
PRESTON 2415 50%
MARION 10085 1%
TAYLOR 174 74%
HARRISON 7163 13%
BARBOUR 3708 63%
TUCKER 570 100%
GRANT 2473 20%
MINERAL 182 44%
MORGAN X
BERKELEY X
JEFFERSON X
HAMPSHIRE X
HARDY X
PENDLETON X
LEWIS 530 02%
UPSHUR 521 42%
GILMER 68 75%
BRAXTON 8 0%
RANDOLPH 563 14%
MASON 339 0% X
PUTNAM 1 0%
CABELL
KANAWHA 11293 12%
CLAY 63 0%
WEBSTER 191 17%
NICHOLAS 6701 6%
POCAHONTAS 54 0% X
WAYNE 14 0%
LINCOLN X
BOONE 10361 12%
LOGAN 14003 2%
MINGO 3549 1%
FAYETTE 5034 25%
GREENBRIER 483 1%
RALEIGH 8710 17%
WYOMING 13304 4%
SUMMERS
MONROE X
McDOWELL 16564 8%
MERCER 1219 15%
MAP OF WEST VIRGINIA SHOWING
COAL PRODUCTION BY COUNTIES AND THE PERCENTAGE OF COAL PRODUCED BY SURFACE MINING IN 1969.
(Production to the nearest thousands of tons and to nearest percent)
82°
81°
80°
79°
78°

FIGURE 26. MAP OF WEST VIRGINIA SHOWING THE PRODUCTION OF COAL BY COUNTIES AND PERCENTAGE OF COAL PRODUCTION BY SURFACE MINING

APPENDIX D

Table 38

Lime requirement by soiltest vs titration.

Tons/Acre

Sample	Soiltest	Titration	Sample	Soiltest	Titration
SCS-1	3.00	0.75	S-2-2	6.75	2.60
SCS-2	3.75	1.20	S-2-3	6.00	3.00
SCS-3	3.00	0.90	S-2-4	6.75	2.90
SCS-4	3.75	1.20	S-2-5	7.50	4.00
SCS-5	4.50	3.00	S-2-6	7.50	3.90
SCS-6	9.00	4.50	P-1-1	9.75	4.60
SCS-7	3.00	1.50	P-1-2	4.50	2.40
SCS-8	4.50	1.50	P-1-3	3.00	1.20
SCS-9	1.50	0.50	P-1-4	3.75	1.60
SCS-10	4.50	1.50	P-1-5	3.00	1.20
SCS-11	4.50	1.50	P-1-6	3.00	1.10
SCS-12	4.50	1.50	P-2-1	4.50	2.00
SCS-13	1.50	0.50	P-2-2	7.50	3.90
SCS-14	4.50	1.50	P-2-3	3.75	1.50
SCS-15	3.00	1.00	P-2-4	5.25	2.70
S-1-1	8.25	4.20	P-2-5	3.75	1.50
S-1-2	6.00	3.70	P-2-6	3.75	1.90

APPENDIX D

Table 38 (continued)

	Tons/Acre				
Sample	Soiltest	Titration	Sample	Soiltest	Titration
S-1-3	9.00	4.00	UF-1-1	7.50	3.10
S-1-4	9.00	4.30	UF-1-2	6.75	3.00
S-1-5	8.25	4.00	UF-1-3	3.75	1.80
S-2-1	6.00	3.00	UF-1-4	3.75	1.60
UF-1-5	3.00	0.90	BK-2-3	5.25	1.90
UF-1-6	3.00	0.90	BK-2-4	10.50	5.40
BK-1-1	9.75	4.80	BK-2-5	9.00	4.00
BK-1-2	8.25	4.60	BK-2-6	8.25	3.50
BK-1-3	6.75	2.10	UF-2-1	5.25	2.60
BK-1-4	5.25	2.10	UF-2-2	3.75	1.70
BK-1-5	6.75	2.90	UF-2-3	2.25	0.80
BK-1-6	6.00	2.60	UF-2-4	3.00	1.50
BK-2-1	11.25	4.90	UF-2-5	2.25	0.90
BK-2-2	10.50	4.90	UF-2-6	2.25	0.80

1 *Accession Number*

2 *Subject Field & Group*

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 *Organization*

Division of Plant Sciences
College of Agriculture and Forestry
West Virginia University
Morgantown, W. Va. 26506

6 *Title*

MINE SPOIL POTENTIALS FOR WATER QUALITY AND CONTROLLED EROSION

10 *Author(s)*

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16 *Project Designation*

EPA,OWP Project No. 14010 EJE

21 *Note*

22 *Citation*

23 *Descriptors (Starred First)*

*Strip mines, *Overburden, *Chemical Properties, *Physical Properties

*Geologic Formations, *Soils, *Weathering, Soil Formation

25 *Identifiers (Starred First)*

Mahoning sandstone, old spoils, Pyritic sandstone

27 *Abstract*

Extensive geologic and soils information and classification provide the basis for applying adapted chemical, physical and mineralogical measurements to selected rock and soil profiles involved in surface mining, and for expanding results to other points or regions for prevention of acid, sediment and other pollution.

With Mahoning sandstone the common weathering depth of 6 meters contains essentially no disseminated pyrite. The originally gray quartzose pyritic sandstone weathers brown, and plant nutrients Ca, Mg, and K are removed by acid leaching. Moderate liming and fertilization of the brown rock and soil enable ground covers to protect spoil surfaces and assure quality waters.

Weathering in spoils, and laboratory simulations, both with and without appropriate chemoautotrophic organisms, reflect rock textures, mineral species, and pyrite oxidation with release of acid. Resulting net acidity or basicity influences soil and water quality.

Old barren spoils confirm that pH is the prime variable associated with lack of vegetation but available water is limiting on sandy, stony, spoils.

Fissile iron ore spoils 70 to 130 years old showed that rooting depths and available water capacities were superior to original soils. Site quality for trees or pasture, and water quality were not significantly different between spoils and natural soils. This report was submitted in fulfillment of Project 14010 EJE under the sponsorship of the Office of Water Programs, Environmental Protection Agency. (Smith-West Virginia)

Abstractor Richard Meriwether Smith

Institution West Virginia University, Morgantown, West Virginia

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